PRECIPITATION AND DROUGHT FREQUENCIES FOR SOUTHWESTERN
KANSAS AS RELATED TO VARIOUS CROP WATER USE RATES

by

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INTRODUCTION

The frequency and quantity of precipitation, a matter of extreme importance to all midwestern states, is of particular importance to the agricultural economy of western Kansas. Efforts to find predictable cycles in annual precipitation amounts have led to considerable speculation as to whether or not identifiable nonseasonal precipitation cycles actually exist. According to Kincer (28), some 138 had been proposed up to 1928, with lengths ranging from short periods of time up to as high as 260 years.[1] This wide range suggests that the causes for variation in annual precipitation amounts lie obscured in a variety of independent variable factors. These circumstances point out the fact that in the absence of cycles which can be measured, explained, and predicted, any study of precipitation amounts must, of necessity, be conducted as though precipitation were the result of chance.

Variability of precipitation amounts is present to a greater degree in seasonal than in annual amounts. Allis (2) aptly describes the precipitation variability with this statement that

> It has been said that the Great Plains can expect at least one gully washer and one drought each year... The extreme variability in rainfall conditions constitutes a serious problem to agriculture in the Great Plains.

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[1]Numbers refer to appended references

This variability in the amount of seasonal and annual precipitation points out the weakness of the mean, or average value, as a measure of the precipitation to be expected within a given time interval. Despite the fact that the mean, or average value, is the most commonly used measure of precipitation to be expected, it is an undesirable measure of precipitation to be expected at any future date because of the inherent variability of precipitation amounts. This fact leads to the conclusion that a more suitable measure of precipitation, both annual and seasonal, would be a frequency array, giving instead of a mean value, the probability of a given amount of precipitation.

The variability of precipitation and the frequency with which it has been insufficient to meet the water needs of growing crops, has led to the development of a considerable number of irrigation systems, particularly in the southwestern part of Kansas. (17, 24, 25) Information relating crop water needs to precipitation amounts available for crop use, on a frequency distribution basis, would assist designers and operators of irrigation systems in estimating irrigation requirements. The same information would be useful to the dry land farmer, in making an estimate of the drought hazard to his enterprise.

PURPOSE

The purpose of this study was to relate various crop water use rates to precipitation and drought frequency in southwestern Kansas through a frequency distribution statistical analysis.

The results of the study are intended to provide climatological information, on a frequency distribution basis, in a form suitable for making estimates of water requirements of crops when the consumptive use is known, cr can be estimated.

REVIEW OF LITERATURE

The basic data used in this study were taken from precipitation records prepared and summarized by the U. S. Weather Bureau, in their reports, "Climatological Data - Kansas Section". (10) Studies on the hydrological aspects of Kansas weather records are summarized by the University of Kansas bulletin (34), Notes of the Hydrology of Kansas. In this publication the probability of given amounts of monthly and annual precipitation are presented. A detailed study of Kansas climate is given in the Report of the Kansas State Board of Agriculture. (9)

More generalized aspects of climatology affecting the Kansas region are given by Haurwitz and Austin (20), in a manner that emphasizes the synoptic patterns of the meteorological elements that produce the climate experienced in the

region by describing the distribution and variation of meteor-
ological elements in terms of frontal and air-mass concepts.
Appended plates in Haurwitz and Austin's text (20) give mean
values of critical meteorological elements which define the
average climate of the globe. The physical processes by which
these elements produce precipitation, as well as other
meteorological processes, are given by Willet (43).

Sub-normal precipitation periods, or droughts, are
discussed by W. G. Hoyt, (23, Chapter XII), J. C. Hoyt, (21),
and others (23, p. 591). Barger and Thom (4) evaluated the
drought hazard through a statistical study of precipitation
amounts and frequencies throughout a crop growing season.
The variability of precipitation in the Great Plains area is
stressed by Allis (2).

In efforts to provide irrigation water for crops to
compensate for the frequent drought periods, irrigation by
pumping began in southwestern Kansas as early as 1888 (17).
Recommendations for pumping equipment were published as early
as 1920 by the Kansas State Board of Agriculture, Division
of Irrigation (24). A later report from the same source (17)
gives a history of the development of irrigation in one county
of southwestern Kansas.

The relation of drought periods in Kansas to supplemental
irrigation was studied during the drought period of the 1930's
by Hulburt (22). The expansion of irrigation practices into

the period of 1947-48 was summarized by the Kansas State
College Extension Service (25).

Early reports on water requirements of crops were pub-
lished as early as 1907 by Fortier (14). Later data published
by the same author gave information on irrigation requirements
in the Arkansas River Basin (13). More recent information
has been included in estimates of crop water requirements by
Israelsen (27, pp 295-316). Blaney and Criddle (5 and 6)
developed a method for estimating water requirements in
irrigated areas from climatological data. The method developed
by Blaney and Criddle has been utilized by Hanson and Meyer
to make estimates of irrigation requirements for various crops
in Kansas. (19)

Climatological data and precipitation data utilized by
these investigators has been summarized by average values.
The weakness of the average as a measure of precipitation,
is pointed out by Foster, (15, p. 106) and emphasized by
Dingle (12), in the following words:

>...One of the basic concepts which has been contrib-
uted by statistical science is that which points out the
meaninglessness of a simple mean in the absence of the
frequency distribution from which it is derived. It
need not be emphasized that for agricultural purposes,
simple monthly means of precipitation and temperature
are of no great value. But if the mean from a given
period is supplemented by some information about the
frequency of occurrence of specific ranges of temperature
and/or precipitation over a given more or less homogeneous
area, some useful information is immediately forthcoming.
From the frequency distributions the probability of oc-
currence of specified precipitation amount and/or tempera-
ture can be computed. By the introduction of the time
element, duration frequencies can be established and used
in a similar way. For example, the probability of a

15 day drought occurring during the month of June over
any specified region can be determined from the duration-
frequency distribution of periods with negligible amounts
of rain. This, then, is approaching the point at which
a farmer's weather risk can be computed for a specified
crop.

The need for a more satisfactory presentation through
a frequency array and analysis is presented by Rouse (36).

In efforts to relate precipitation data to water require-
ments of crops, Barger and Thom (3) studied the correlation of
precipitation to corn yields to obtain a measure of drought
intensity.[1] Hulburt (22) studied drought periods in Kansas
through an arbitrary index of "Effective Rainfall", and
reported on the frequency of times in 20 years in which
monthly rainfall amounts were less than one-half the average
amounts.

Information relating various crop water use rates to
precipitation and drought frequency in southwestern Kansas
through a frequency distribution statistical analysis is
presented in this thesis.

MATERIAL AND METHODS

Measures of Drought Intensity

In efforts to study the magnitude and frequency of drought
periods, various measures of drought intensity, and varying
definitions of droughts have been proposed. Drought studies

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[1]Water requirements defined as in Appendix A.

undertaken by Hoyt after the severe droughts of the 1930's, showed drought conditions whenever there was an annual deficiency in precipitation of 15 percent or more (Hoyt, 21). Other investigators have proposed an index of 75 percent of normal annual precipitation; also an index of 4 month droughts in which precipitation during each month was less than 60 percent of normal precipitation for that month (35).

Other studies (23, p 584) show that annual precipitation has been less than the needs for evaporation and transpiration approximately 20 percent of the time in eastern Kansas, and more than 90 percent of the time in extreme western Kansas.

For the purpose of this study, Hoyt's (21) definition of a drought is accepted: "Drought conditions may be said to prevail whenever precipitation is insufficient to meet the needs of established human activities." Applying Hoyt's definition of drought to the production of agricultural crops, a drought condition may be said to exist whenever there is not sufficient precipitation to maintain satisfactory plant growth.

The "Bank Account Procedure"

Other investigators (30 and 40) have applied evapotranspiration estimates to a "bank account procedure" to determine the time for irrigation.[1] The explanation of this

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[1]Evapo-transpiration defined as in Appendix A.

system is described by von Bavel and Wilson (40) as follows:

> ...if the quantities of water added to the soil were
> known, and if the total daily evapo-transpiration amounts
> were known, a simple bank account procedure could be
> used to determine the readily available supply of water
> in the soil at any time. When this supply appears to
> be reduced to zero, or nearly so, the need for irrigation
> is indicated.

Allred and Chen (1) applied a similar procedure to an
evaluation of irrigation needs in the Minnesota region.
Their procedure included a method of computing daily moisture
deficiency through utilization of IBM punched cards. The
basis for the computation was a daily balancing of crop
water use against available moisture in the root zone.

This "bank account procedure" was applied in this study.
Daily water use rates of .05, .10, .20, and .30 inch per day
were assumed, and a "bank account procedure" was applied to
daily precipitation records for ten stations in southwestern
Kansas, for thirty years of record from each station. Through
this "bank account procedure" the number of "dry days" were
determined for each water use rate for each of the 30 years of
record, 1923 through 1952.[1]

Areas and Stations Selected for Study

The southwestern section of Kansas was selected for study
because of the concentration of irrigation enterprises in
that section of the state. A 1948 survey (25) showed approxi-

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[1]Dry days defined as in Appendix A.

mately 90 percent of all irrigated acres in Kansas within
the southwestern section of the state. Between 1948 and 1954
the total number of acres under irrigation in Kansas nearly
doubled but the nineteen southwest counties still had about
80 percent of the total irrigated acreage. (41, p. 53)
Stations within the area were selected to give as uniform
coverage as possible of the southwestern section, including
the following counties: Finney, Ford, Grant, Gray, Greely,
Hamilton, Haskell, Kearny, Lane, Meade, Morton, Scott, Seward,
Stanton, Stevens, and Wichita. Stations within this area were
selected for study on the basis of adequate length of record
and uniform coverage of the area. The ten stations selected
were: Cimmaron, Dodge City, Garden City, Healy, Johnson,
Liberal, Richfield, Scott City, Sublette, and Tribune.

The area of Southwestern Kansas selected for study, and
the stations from which precipitation records were analyzed,
are shown on Plate I.

Frequency Analysis

A frequency analysis was made of the dry days data
obtained by the bank account procedure described above.[1]
The result was to give the percentage probability of having a
given number of dry days per month for each station for each
month for each applicable water use rate. Individual stations

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[1]Dry days defined as in Appendix A. Throughout this thesis ,
the term "dry days" will be used in the sense as defined in
Appendix A.

EXPLANATION OF PLATE I

Map showing the area in southwestern Kansas selected for
study, and the stations within the area from which precipi-
tation records were analyzed.

PLATE I
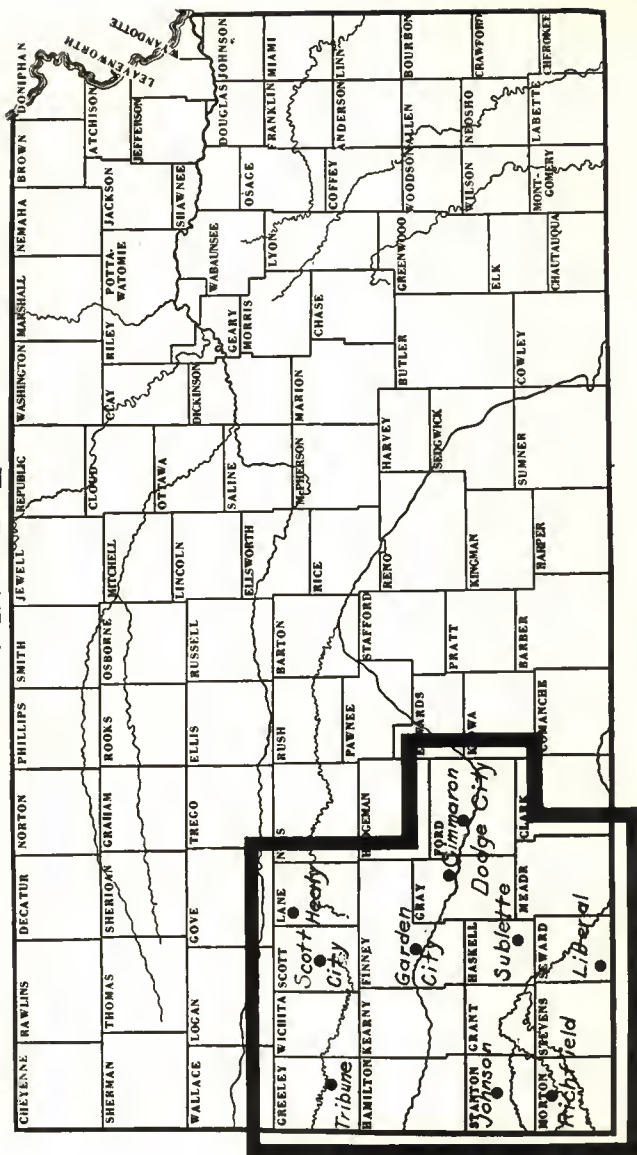
were later combined to give a similar frequency analysis of
dry days for sections of southwestern Kansas in an attempt to
give greater statistical validity to the study by combining
stations within a section to obtain a greater number of
station years of record.

Water Use Rates

The water use rates of .05, .10, .20, and .30 inch per
day were used in an attempt to "bracket" the water use rates
of any crops grown within the southwestern Kansas area. Rates
used for each month are given in Table 1. It will be noted
from Table 1 that dry days frequency for all four water use
rates was not determined for each month. The lower use rates
of .05 and .10 inch per day were determined for the spring and
fall seasons, while the higher use rates of .10, .20, and .30
inch per day were computed for the summer months. This
procedure was followed in an effort to simulate the higher
water use rates that occur during the summer months.

Assumptions Made in Counting Dry Days

Following are the assumptions made in counting dry days.
1. Daily precipitation amounts were rounded off to the
nearest .05 inch for the water use rates of .05 inch per day;
to the nearest .10 inch for the water use rate of .10 inch
per day; to the nearest .20 inch for the water use rate of
.20 inch per day; and to the nearest .30 inch for the water use
rate of .30 inch per day .

Table 1. Crop daily water use rates used in dry days
          frequency study.

Month	Rates Used, inch per day			
April	.05	.10		
May	.05	.10	.20	
June		.10	.20	.30
July		.10	.20	.30
August		.10	.20	.30
September	.05	.10		
October	.05	.10		

2. The assumption was made that not more than 2.00 inches
of precipitation would be credited to the "soil moisture account"
in any 24 hour period. This assumes that amounts in excess
of 2.00 inches within a 24 hour period would be lost as runoff
in high intensity rains typical of the summer time thunder-
storm precipitation of the southwestern Kansas area. Analysis
of the diurnal precipitation distribution (9, p. 56) for
Dodge City, typical of the southwestern Kansas area, shows
a distinct precipitation maximum in early evening for the
summer season, and, to a lesser extent, for the spring and
fall seasons. This is also in agreement with Willet's
observation (Willet, 43, p. 161-2) that

> ...The effect (of the summertime circulation over
> the United States) is to increase the rainfall signifi-
> cantly in most sections east of the continental divide...

(and cause)...widespread occurrence of thunderstorms
and heavy local convective rains due to the continental
heating of the moist air.

3. The assumption was made that not more than 12.0
inches of water could be credited to the "soil moisture
account" at any one time. This represents (Israelsen, 27,
p. 216) an extreme upper limit of available water that may
be stored in a medium to heavy textured soil for a root zone
of six feet.

4. The assumption was made that 50 percent of the
precipitation from the months of November through March was
lost to the "soil moisture account" through evaporation.
Therefore soil moisture stored in the "soil moisture account"
as of April 1 of each year was assumed to be 50 percent of
the total precipitation for the months of November through
March, plus the carryover of soil moisture from 31 October of
the previous year at the 0.10 inch per day water use rate.

5. The assumption was made that the soil moisture stored
in the "soil moisture account" as of the first of each month
from May through October was that quantity of soil moisture
remaining at the end of the previous month. Table 2 illustrates
the method used in determining the amounts of soil moisture
available at the beginning of any month for any water use rate.

6. The assumption was made that water used by crops on
any day was subtracted from precipitation that fell during that
day, with the balance of the precipitation, if any, stored
in the "soil moisture account". Thus, at a water use rate of

0.05 inch per day, if there were no moisture stored in the
"soil moisture account", and 0.50 inch of rain fell on the
first of the month and none for the rest of the month, the
first dry day would be the 11th of the month, and there
would be a total of 20 dry days in the month (30 day).

Table 2. Data used in determining soil moisture available at
the beginning of each month of the growing season.

At beginning of month of	Considering a use rate of (in. per day)	The available moisture was determined from carry-over	
		From the end of the month of	At water use rate of (in.per day)
May	.05	April	.05
May	.10	April	.10
May	.20	April	.10
June	.05	May	.05
June	.10	May	.10
June	.20	May	.20
June	.30	May	.20
July	.10	June	.10
July	.20	June	.20
July	.30	June	.30
August	.10	July	.10
August	.20	July	.20
August	.30	July	.30
September	.05	August	.10
September	.10	August	.10
October	.05	September	.05
October	.10	September	.10

Sample Calculations Illustrating Counting
of Dry Days

Sample calculations illustrating the method used in
counting dry days are given in Appendix B-1 and B-2.

Data Available After Completion of
Dry Days Count

After completion of the count of dry days, as described
above, the number of dry days for each of the months, April
through October, at the water use rates indicated, .05 to .30
inch per day, for each of the 30 years of record for each of
the ten stations, was available.

Method of Combining Data into Frequency
Analysis of Dry Days

After completion of the count of dry days, the data were
arranged in an array from low to high for each station, for
each month, for each water use rate, for the 30 years of
record, and plotted on probability scale vs. arithmetic scale
graph paper. The completed graphs are given in Figs. 1
through 40 in the Appendix.

Sample calculations illustrating the method used in
combining data from single stations into an array for frequency
analysis are given in Appendix B-3.

Method of Dividing Southwestern Kansas into Sections of Similar
Rainfall Characteristics for Grouping of Data for Greater
Statistical Validity

The Problem. In order to group the data from several
stations to provide a greater number of station years of
record for greater statistical validity, it was necessary to
determine whether or not the entire southwestern Kansas area
could be subdivided into sections of similar dry days
characteristics. Stations within each subdivision could
then be combined to provide a record with a greater number of
station years of record.

Discussion. Records of annual precipitation, seasonal
precipitation, and monthly precipitation in the "Climate of
Kansas" (9) show a general decrease in normal precipitation
from east to west throughout the western section of Kansas.
This general decrease of precipitation from east to west
might also be deduced from the fact that the mean atmospheric
circulation is such that moisture from the Gulf of Mexico
would be brought in greater amounts to eastern Kansas than to
the western part of the state (Haurwitz and Austin, 20, Plates
B and A; Plates V and IV). With this general knowledge, the
problem became one of determining whether or not a comparable
east to west pattern held for the dry days as used in this
study.

Method. The following method of analysis was used. On
sectional maps of southwestern Kansas, the percent of time

that less than one dry day occurred at a water use rate of
.05 inch per day was plotted for the months of April, May,
June, September and October beside each of the ten stations
studied. (This information is shown on Fig. 62.) Data
plotted were taken from the frequency distribution graphs
for the .05 inch per day use rate from Figs. 1, 5, 9, 14,
17, 21, 25, 29, 33, and 37. Iso-lines for equal percentages
were drawn for each of the months. The completed chart was
then examined for suitable subdivisions of similar dry day
characteristics.

Results. A general decrease in moisture from east to
west could be noted from analysis of the iso-lines. No
noticeable gradient could be found from south to north. The
following subdivisions were selected as having similar dry
day characteristics.

Western Section	Central Section	Eastern Section
Counties:		
Greely	West halves of:Finney	East halves of:Finney
Hamilton	Scott	Scott
Stanton	Haskell	Lane
Morton	Seward	Gray
West halves of:	East halves of:	Ford
Wichita	Wichita	Meade
Kearny	Kearny	
Grant	Grant	
Stevens	Stevens	
Stations:		
Tribune	Garden City	Healy
Johnson	Sublette	Scott City
Richfield	Liberal	Cimmaron
		Dodge City

A map showing the division of southwestern Kansas into sections
is given in Fig. 62 in the Appendix.

Since these subdivisions based on the .05 inch per day use rate, were so similar to the pattern that would be expected based on the mean circulation of the atmosphere over the area as well as from annual and seasonal precipitation patterns, the assumption was made that the dry days distribution for water use rates of .10, .20, and .30 inch per day would fall within the same subdivisions of similar rainfall characteristics.

Combination of Single Station Dry Days Frequency Data into
Frequency Data for Western, Central, and Eastern Sections of
Southwestern Kansas

The method used to combine the single station frequency analyses into frequency analyses for sections of southwestern Kansas follows the method developed by Jones (34, p. 29). The frequency with which a given number of dry days occurred for each of the stations within the section were compiled and then combined to give the probability of occurrence for the section as a whole. Appendix B-4 illustrates this procedure for the central section for the month of June for the .20 inch per day water use rate.

Data Available after Combination of Dry Days
Frequency Data by Sections

After the single station dry days frequency data had been combined into frequency data for the western, central and eastern sections of southwestern Kansas, dry days frequency data were plotted for each section, for each month, for each applicable water use rate.

BODY

Analysis of Dry Days Frequency Data for
Single Stations

The completed frequency analysis of dry days, for single stations, is presented in the graphs, Figs. 1 through 40 in the Appendix. Each of these graphs presents, for one station, the percentage probability of having a given number of dry days per month for a given water use rate for each of the months of the growing season. Table 3 illustrates some of the information that may be obtained from Fig. 10. (Garden City, Kansas, .10 inch per day water use rate.)

Table 3. Illustration of information available from Fig. 10, dry days frequency study, Garden City, Kansas, .10 inch per day water use rate.

Month	Percent of time less than one dry day per month will occur	Maximum number of dry days per month to be expected 90% of the time
April	54	19
May	51	21
June	61	15
July	54	20
August	47	20
September	51	20
October	41	28

Analysis of Dry Days Frequency by Sections

The completed frequency analysis of dry days by sections
is presented in the graphs, Figs. 41 through 61 (Appendix).
Each of the graphs presents, for the given section for the
given month, the percentage probability of having a given
number of dry days per month for the water use rates indicated.
Table 4 illustrates some of the information that may be
obtained from Fig. 43. (Dry days frequency study, eastern sec-
tion of SW Kansas, June)

Table 4. Illustration of information available from Fig. 43,
dry days frequency study, Eastern section of SW Kansas, June.

Use rate in. per day	Percent of time less than one dry day per month will occur	Maximum number of dry days per month to be expected 90% of the time
.05	96	0
.10	75	8
.20	21	23
.30	10	26

DISCUSSION: UTILIZATION OF DATA

General

The primary utilization of the data presented in this
report lies in making an estimate of water requirements on
a probability basis when the consumptive use is known, or can

be estimated. A further use of these data lies in making an estimate of the probability that natural precipitation would supply the water that could be applied by winter irrigation. An evaluation of the drought hazard to dry land crops may also be made through these data when water requirements of the crop are known.

Example 1. Making an Estimate of Irrigation Requirement on a Probability Basis when the Consumptive Use Can be Estimated

Consumptive use estimates for this example for the Garden City area are taken from Hanson and Meyer's "Irrigation Requirements Estimates for Kansas" (Hanson and Meyer, 19, pp. 8, 9).

For alfalfa, the monthly consumptive use is .85 times the monthly consumptive use factor. Thus the monthly consumptive use for alfalfa may be computed. Table 5 illustrates the computation of irrigation requirements for alfalfa for probabilities of 10, 50, and 90 percent.

This example shows seasonal irrigation requirements of 3.5, 16.3 and 27.6 inches for probabilities of 10, 50 and 90 percent, respectively. Other probabilities could be computed through a similar procedure. Frequency data from Figs. 9 through 12 in the Appendix (Dry days frequency analysis for Garden City) could also have been used in making this estimate.

Table 5. Computation of irrigation water requirements for Garden City area for crop of alfalfa for probabilities of 10, 50, and 90 percent.

Month	Monthly consumptive use factor (1)	Monthly consumptive use, inches (2)	Number of days (3)	Average daily use rate (4)	10% Prob Dry days (5)	10% Prob Irrigation requirement (6)	50% Prob Dry days (5)	50% Prob Irrigation requirement (6)	90% Prob Dry days (5)	90% Prob Irrigation requirement (6)
Apr.(4 days)	.64	.54	4	.135	$0 \cdot \frac{4}{30} = 0$	0	$0 \cdot \frac{4}{30} = 0$	0	$20 \cdot \frac{4}{30} = 2.7$	.36
May	6.32	5.37	31	.173	0	0	9	1.56	24.5	4.24
June	7.30	6.20	30	.21	0	0	14.5	3.05	26	5.46
July	7.97	6.77	31	.22	9	1.98	20	4.40	28	6.16
August	7.37	6.26	31	.20	7.5	1.50	20	4.00	27.5	5.50
September	5.83	4.96	30	.165	0	0	15	2.475	26	4.29
Oct.(14 days)	1.99	1.69	14	.12	$0 \cdot \frac{14}{31} = 0$	0	$15 \cdot \frac{14}{31} = 6.7$	.80	$30 \cdot \frac{14}{31} = 13.5$	1.62
Totals:		31.79				3.48		16.28		27.63

(1)Reference 19, table 2
(2)(.85)(Monthly consumptive use factor)
(3)In frost free season
(4)= (2) ÷ (3)
(5)Dry days, from figures 48 through 54 "Dry days frequency analysis for central section of SW Kansas
(6)Irrigation requirement for month = (5)(4).

Example 2. Making an Estimate of the Probability that Natural
Precipitation Would Supply the Water that Could Be Applied By
Winter Irrigation

For this example, Hanson and Meyer's data (19, pp.8, 9)
will again be used, for a crop of small grain, making the
modification that the April use rate will be .05 inch per
day for the entire month. Table 6 illustrates the procedure
for computing the probability of having no dry days per month
for each of the months. Under these conditions, natural
precipitation would then supply the needs of the crop. The
probability of five dry days or less per month is also given
in Table 6.

Thus the probabilities of having no dry days for the
months of April, May, and June are 78, 39 and 29 percent,
respectively, for the water use rates indicated, for small
grain in the Garden City area. The probabilities of having
five dry days or less are 85, 49 and 36 percent, respectively.

Example 3. Making an Estimate on a Probability Basis of Water
Requirements for Winter Irrigation

A similar procedure may be used to make an estimate of
the water that should be applied by winter irrigation to
fulfill the requirements of the crop for a given percentage
probability. This procedure, at the 50 percent probability
level, is given in Table 7.

Thus the total winter irrigation requirement to maintain
a crop of small grain during the spring season 50 percent of

Table 6. Computation of probability of having no dry days during spring months for crop of small grain in Garden City area.

Col. 1	2	3	4	5	Percent Probability(5) of no dry days at water use rates of:				Percent Probability of five dry days or less at use rates of:			
Month	Monthly consumptive use factor(1)	Monthly consumptive use, inches(2)	Number of days	Average daily use rate (inch per day)(3)	.05 inch per day	.10 inch per day	.20 inch per day	Interpolated for use rate indicated in column 5	.05 inch per day	.10 inch per day	.20 inch per day	Interpolated for use rate indicated in column 5
					6	7	8	9	10	11	12	13
April	-	-	30	.05	78(4)	-	-	78	85	-	-	85
May	6.32	4.74	31	.15	-	48	29	39	-	60	38	49
June	7.30	5.48	30	.18	-	55	12	29	-	75	27	36

(1)Reference 19, table 2.
(2)= (.75)(monthly consumptive use factor)
(3)= (2) ÷ number of days in month
(4)Estimated at 0.05 inch per day for April.
(5)Values taken from figures 9 through 12, single station dry days frequency data for Garden City.

Table 7. Computation of winter irrigation requirements,
on 50 percent probability basis, for small grain,
for Garden City area.

| Col. | Month | Use rate, inch per day(1) | Dry days to be expected(2) 50 percent of time for use rates of | | Interpolated for use rate indicated in column 2. | Irrigation requirement(3) |
			.10 inch per day	.20 inch per day		
Col.	1	2	3	4	5	6
	April	.05			0	0
	May	.15	0	11	5.5	.82
	June	.18	0	15	12	2.16
					Total:	2.98

(1)From Table 6, column 5, example 2, preceding.
(2)Values taken from figures 9 through 12, single station dry
days frequency study for Garden City.
(3)Irrigation requirement = column 5 X column 2.

the time, for the Garden City area, is 2.98 inches. Irrigation requirements on a different probability basis could be determined in a similar manner.

Example 4. An Evaluation of the Drought Hazard to Dry Land Crops

Data from example 2 (Table 6) may also be used to illustrate a method of evaluating the drought hazard to dry land crops. Using the probability figures of 85, 49, and 36 percent for the probabilities of having five dry days or less for small grain in the spring season of April, May, and June, respectively, in the Garden City area, the product of these percentage probabilities becomes the probability of passing through all three months with less than five dry days in each.[1]

Thus, (.85)(.49)(.36) = .150, or 15.0 percent of the time there would be sufficient natural precipitation to fill the needs of the crop of small grain during these months so that not more than five dry days would occur in each month.

A similar calculation, (.78)(.39)(.29) = .088 or 9 percent of the time there would be sufficient natural precipitation

---

[1] This assumes that the dry days frequency data for each month is independent of the other months. This theorem is stated in a standard algebra text as follows: "If the probability of success...of a first event is p_1, and if after this event has resulted in success...,the probability of success... of a second event is p_2, the probability that both events will result in success...in the order stated is $p_1 p_2$...Note: (this theorem) and its proof can be extended to more than two events." Joseph B. Rosenbach and Edwin A. Whitman, College Algebra, Revised Edition, p. 354.

to meet the need of the crop with no dry days throughout the
spring growing season.

RECOMMENDATIONS FOR FURTHER STUDY

Correlation of Dry Days to Average Monthly Precipitation and Application to Other Areas

It may be noted that the frequency distribution curves
presented in this study, Figs. 1 through 61, all have a
similar characteristic shape. When plotted on arithmetic vs.
probability graph paper, a characteristic curve rises upward
to the right as nearly a straight line from a small number of
dry days, and then at a higher probability, becomes asymptotic
to the horizontal line representing the total number of
days in the month.

Because of this characteristic shape, it would seem
reasonable that the dry days frequency as used in this study,
could be correlated to a more commonly used and readily
available value, such as the average monthly precipitation.
If such a correlation could be made it would be possible to
extend the dry days frequency data, available in this study,
over a limited area, to other areas outside the boundaries
of this study. Such a correlation would have the added
advantage of a considerably smaller amount of time required
than that required for the type of frequency analysis presented
in this study.

Relation of Irrigation Equipment Design to
Dry Days Frequency

It was not the purpose of this study to attempt an analysis
of irrigation equipment and costs. It is pointed out, however,
that the dry days frequency analysis, as presented in this
study, provides information upon which to make reasonable
estimates of the irrigation requirements of crops on a proba-
bility basis, within the southwestern Kansas area. A com-
parison of cost of irrigation equipment with sufficient capacity
for providing sufficient water for a probability of, say,
90 percent, may show little significant increase in cost over
a system designed to provide adequate protection on a 50
percent probability basis. Likewise, the cost of a system
designed for the 90 percent frequency level may show a signifi-
cant economy over the system designed for the 100 percent (no
rain) frequency. Further study along these lines should be
of value in selecting a best design for a given unit.

SUMMARY OF RESULTS

This study has presented a method for analysis of drought
and precipitation frequencies as related to crop water use rates.

Through a "bank account" procedure, the number of moisture
deficient "dry days" for crop water use rates of .05, .10,
.20, and/or .30 inch per day was determined for the growing
season in southwestern Kansas. These data were combined

into a frequency array for each of ten individual stations, and is presented in Figs. 1 through 40 in the Appendix.

Data from individual stations were combined into sections of similar rainfall characteristics and are presented in a frequency array in Figs. 41 through 61.

Examples showing how this data may be utilized, and recommendations for further study, are presented.

ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX A - DEFINITIONS

1. <u>Water Requirements</u>: The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. This includes surface evaporation and other economically unavoidable wastes, usually expressed in depth (volume per unit area) for a given time. (American Society of Agricultural Engineers.)

2. <u>Consumptive use, or evapo-transpiration</u>: The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue, and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area. (American Society of Agricultural Engineers.)

3. <u>Dry Day</u>: One day in which the soil moisture reservoir had no available moisture for plant growth. Thus two dry days would represent a deficit of twice the daily crop water use rate, three dry days a deficit of three times the daily water use rate, etc. For example, three dry days at a crop water use rate of 0.10 inch per day would represent an accumulated moisture deficit of .30 inch; or at a water use rate of .05 inch per day, a deficit of .15 inch.

APPENDIX B. SAMPLE CALCULATIONS AND PROCEDURES

Appendix B-1 Sample Calculations Illustrating
Method of Counting Dry Days

Station: Garden City
Year: 1929-1930
Water use rate: .10 inch per day

1. Sum of precipitation, January through March, 1930 = 0.68 in.

2. Sum of precipitation, November and December, 1929 = 2.26 in.

3. Total "winter" precipitation (1 ≠ 2)   2.94 in.

4. 50 percent of winter precipitation   1.47 in.

5. Carryover of available soil moisture from October,

1929. (Computed in same manner as carryover from

October, 1930, below)   1.2 in.

6. Sum of item 4 plus item 5. (This is the computed   2.67 in.

amount of available soil moisture as of 1 April 1930.)

7. Using the "bank account" procedure, count dry day periods

from daily precipitation amounts as follows: (See Appendix B-2

for daily rainfall amounts)

  a. As of 1 April, 2.67 inches of moisture were available
in the soil moisture "bank account". Rounding this value off
to the nearest 0.10 inch gives 2.7 inches available.

  b. By 15 April, at 0.10 inch per day use rate, 1.5
inches would have been used and 2.7 - 1.5 = 1.2 inches would
remain in the "bank account".

  c. On 16 April, 0.27 inch of rain fell. Rounding out to
the nearest 0.10 inch gives 0.30 inch. Assuming crop use of

0.10 inch per day leaves 0.20 inch to add to the soil moisture bank account. Total amount stored at the end of 16 April would then be $1.2 \neq 0.2 = 1.4$ inches.

d. In a similar manner, at the end of 17 April, 1.6 inches would be in the soil moisture "bank account".

e. From 18 through 25 April, 8 X 0.10 = 0.80 inch of water would be used at 0.10 inch use rate. Balance remaining would be $1.6 - 0.80 = 0.80$ inch remaining in storage.

f. At the end of 30 April, 1.3 inches would be stored in the soil moisture "account".

g. This procedure is summarized in the tabulation below. For April, at the 0.10 inch per day use rate, there were no separate dry day periods; total dry days for the month was zero; and 1.3 inches of moisture was available for carryover at the end of the month.

h. A similar process shows that July had three dry day periods of 1, 2, and 4 days each, totaling seven dry days for the month. Sufficient precipitation occurred, however, to leave 1.2 inches available in storage for carryover at the end of the month of July.

Month	Separate dry days periods (days)	Total dry days for month	Carryover at end of month, inches
April	0	0	1.3
May	0	0	1.9
June	0	0	0.6
July	1, 2, 4	7	1.2
Aug.	2,5, 1, 2	10	0.3
Sept.	0	0	0.6
Oct.	0	0	4.1

8. Carryover of soil moisture at the end of October: 4.1 in.

9. This is a sample computation for one year only. A similar computation was performed for each of the thirty years of record 1923 through 1952.

Appendix B-2   Garden City Precipitation Amounts, 1930.

	April	May	June	July	Aug.	Sept.	Oct.
1		.15	.10				T
2		.15				T	T
3						.38	1.55
4		1.18	.17				1.47
5			1.18			.40	.37
6						.93	
7				.17		.06	
8				.05			
9						1.52	
10		.10		.12			
11		.34					2.00
12							1.03
13				.41			T
14		.05			.13		.07
15		.90			.17		
16	.27	.16					
17	.27	.20	.06				
18	T	.07			.03		
19			.12				
20							T
21				.73			T
22				.38	.06		T
23				.30			
24					.25		
25				.41			
26	.62						
27							
28	.03						
29		.15	T		.29		
30	.38	T			.19		
31				.41			
Total:	1.57	3.45	1.63	2.98	1.12	3.29	6.49

Monthly Precipitation Amounts, Winter Season

Month	Total	
Jan.	.50	
Feb.	.18	
March	T	
Nov.	2.05	(1929)
Dec.	.21	(1929)

Appendix B-3 Sample Calculations Illustrating the Method Used
in Combining Single Station Data into an Array for
Frequency Analysis

(Garden City; Month of June; .10 in. per day, use rate)

Array of Data - Low to High

Year	June dry days[1]	Order No.	Dry Days[1]	Plotting point,%[2]
1923	0	1	0	1.67
1924	0	2	0	5.00
1925	0	3	0	8.33
1926	5	4	0	11.66
1927	1	5	0	15.00
1928	0	6	0	18.33
1929	0	7	0	21.67
1930	0	8	0	25.00
1931	0	9	0	28.33
1932	3	10	0	31.67
1933	16	11	0	35.00
1934	16	12	0	38.33
1935	5	13	0	41.67
1936	0	14	0	45.00
1937	0	15	0	48.33
1938	7	16	0	51.67
1939	20	17	0	55.00
1940	0	18	0	58.33
1941	0	19	1	61.67
1942	0	20	3	65.00
1943	4	21	3	68.33
1944	0	22	4	71.67
1945	3	23	5	75.00
1946	0	24	5	78.33
1947	0	25	7	81.66
1948	14	26	14	85.00
1949	0	27	14	88.33
1950	14	28	16	91.67
1951	0	29	16	95.00
1952	0	30	20	98.33

[1]Determined as in Appendix B-2
[2]Plotting point: Plotted at midpoint. Since total
record = 30 years, 1 year - 100 ÷ 30 = 3.33%.

Appendix B-4 Sample Calculations Showing Procedure for Combination of Single Station Dry Days Frequency Analyses into Sectional Dry Days Frequency Analysis

Central Section of SW Kansas, month of June, .20 inch per day use rate.

Z (1)	Dry Days Per mo. (2)	f = Frequency of occurrence (3)	(4)	(5)	(cum f)$_Z$ Cum.Freq. (6)	(cum f)$_Z$/ (cum f)$_{Z-1}$ (7)	Pa, plotting pt. (8)
1	0	4	6	4	14	14	08
2	1	1	1		16	30	17
3	2	1		1	18	34	19
4	3	1			19	37	21
5	4	1	1	1	22	41	23
6	5		1		23	45	25
7	6	1	3	1	28	51	28
8	7		1	1	30	58	32
9	8	1		1	32	62	34
10	9	1		1	34	66	37
11	10	1		2	37	71	40
12	11	1	1		39	76	42
13	12	1		2	42	81	45
14	13		1		43	85	47
15	14	1	1	2	47	90	50
16	15	2	1		50	97	54
17	16	0	0	0	50	100	56
18	17		1	3	54	104	58
19	18	2	1	1	58	112	62
20	19			1	59	117	65
21	20	1	2	1	63	122	68
22	21	2			65	128	71
23	22	1	3		69	134	75
24	23	2		1	72	141	78
25	24	4	2	1	79	151	84
26	25		2	2	83	162	90
27	26	1		1	85	168	93.3
28	27			1	86	171	95
29	28				86	172	95.5
30	29		1	2	89	175	97.3
31	30		1		90	179	99.4

(1) Order number
(2) Determined by the method illustrated in Appendix B-1 and B-2
(3) For Garden City
(4) For Liberal
(5) For Sublette
(6) Sum of col (3) ⁄ (4) ⁄ (5).

(7) Pa = col 7 + 180 = percent probability of having given number of dry days per month.

Note: This system of preparing data for plotting is a simplified version of that presented by Jones (32, page 29).

Following Jones notation,

Z = order number.

f = frequency of occurrence of the given phenomena, in this case the frequency of a given number of dry days per month.

$(\text{cum } f)_Z$ = accumulated frequency of occurrence from $Z = 0$ to $Z = Z$.

$(\text{cum } f)_{Z-1}$ = accumulated frequency of occurrence from $Z = 0$ to $Z = Z - 1$.

N = total frequency = Σf.

Then, by Jones definition,

$$n = \frac{(\text{cum } f)_Z + (\text{cum } f)_{Z-1} + 1}{2}$$

and

$$Pa = \frac{2n - 1}{2N}, \quad \text{where Pa is probability for plotting on probability graph paper.}$$

Combining the equations for n and Pa yields the following relation

$$Pa = \frac{2n - 1}{2N} = \frac{2\left[\frac{(\text{cum } f)_Z + (\text{cum } f)_Z + 1 + 1}{2}\right] - 1}{2N}$$

$$Pa = \frac{(\text{cum } f)_Z + (\text{cum } f)_{Z-1}}{2N}$$

This is the simplified equation used in calculating Pa in this study.

APPENDIX C. FIGURES

Fig. 1. Dry days frequency for Cimmaron. Water use rate .05" per day.

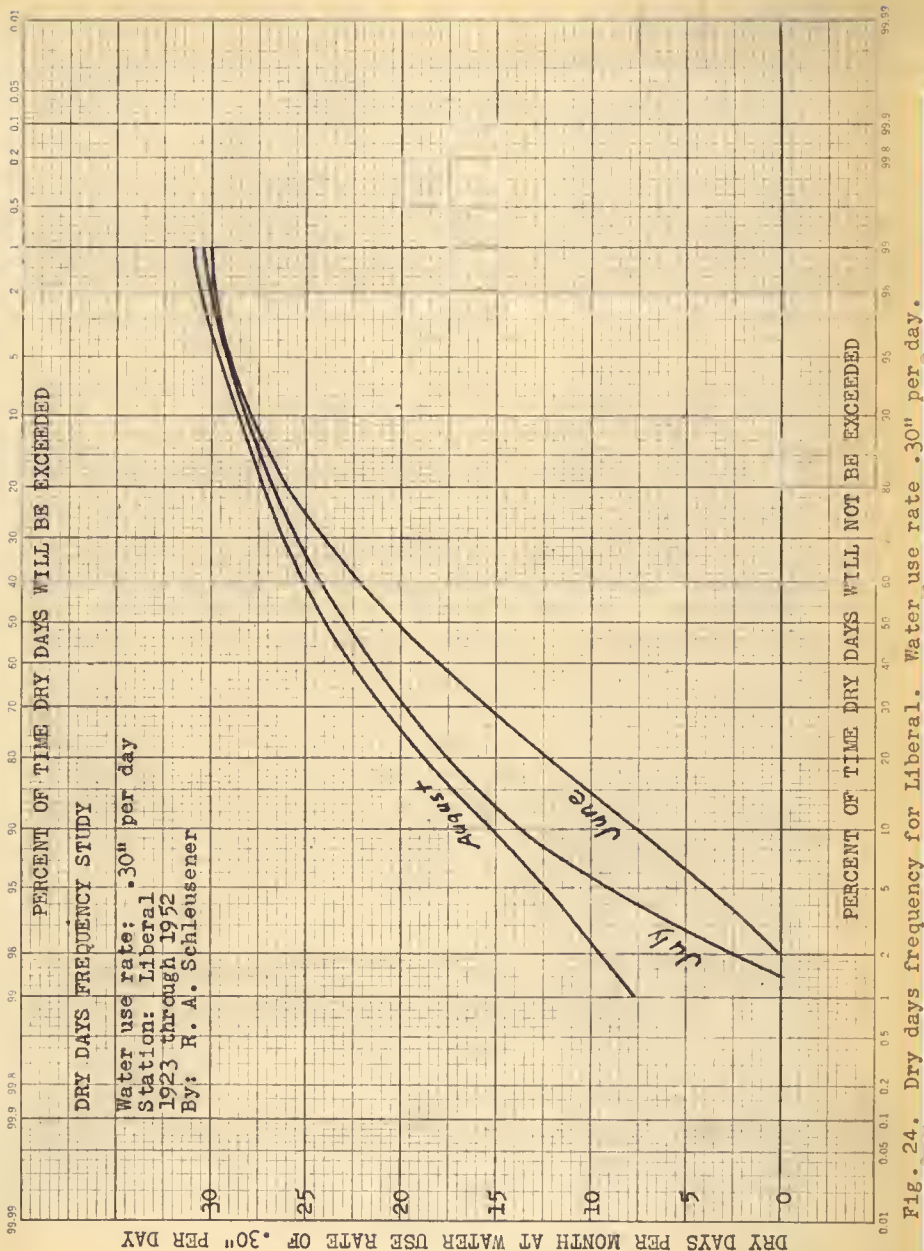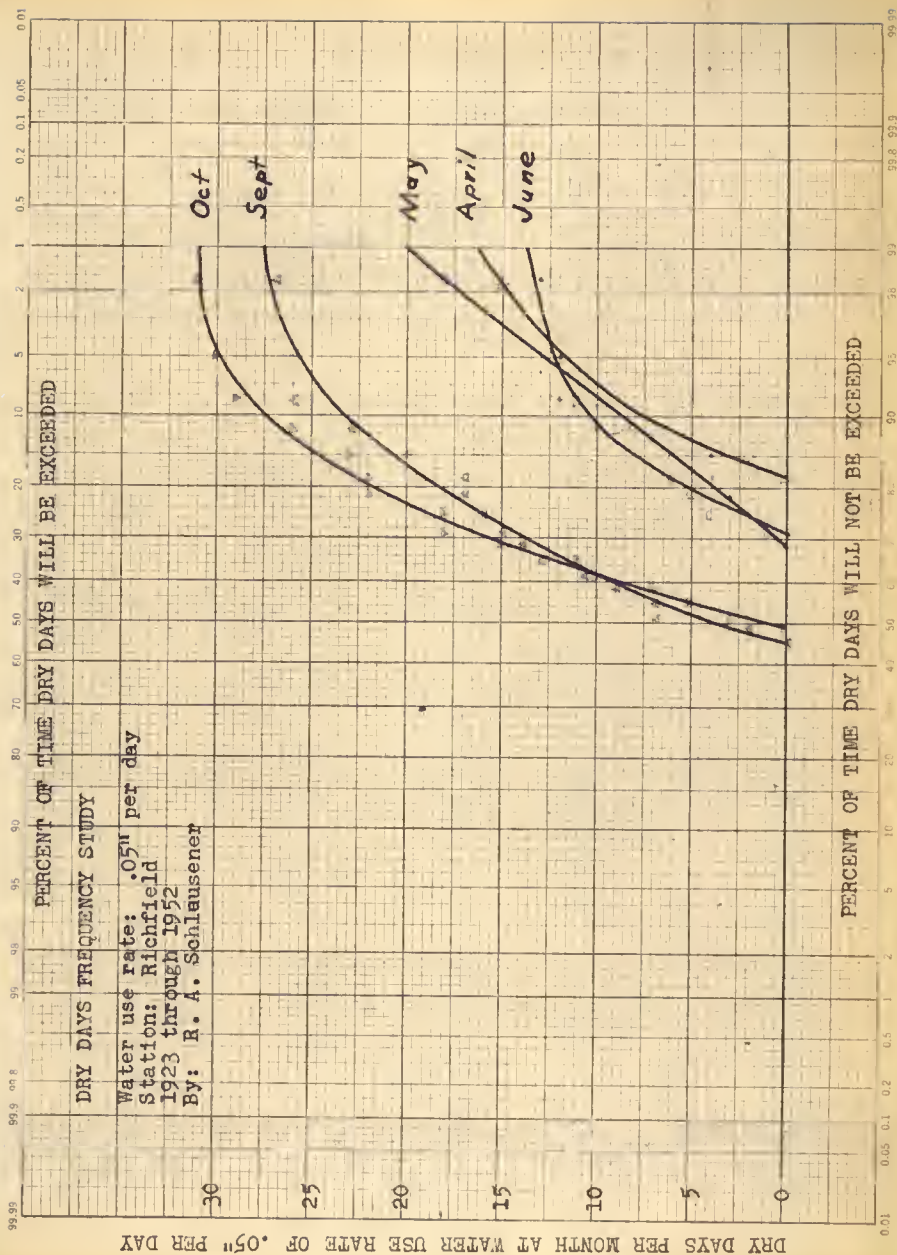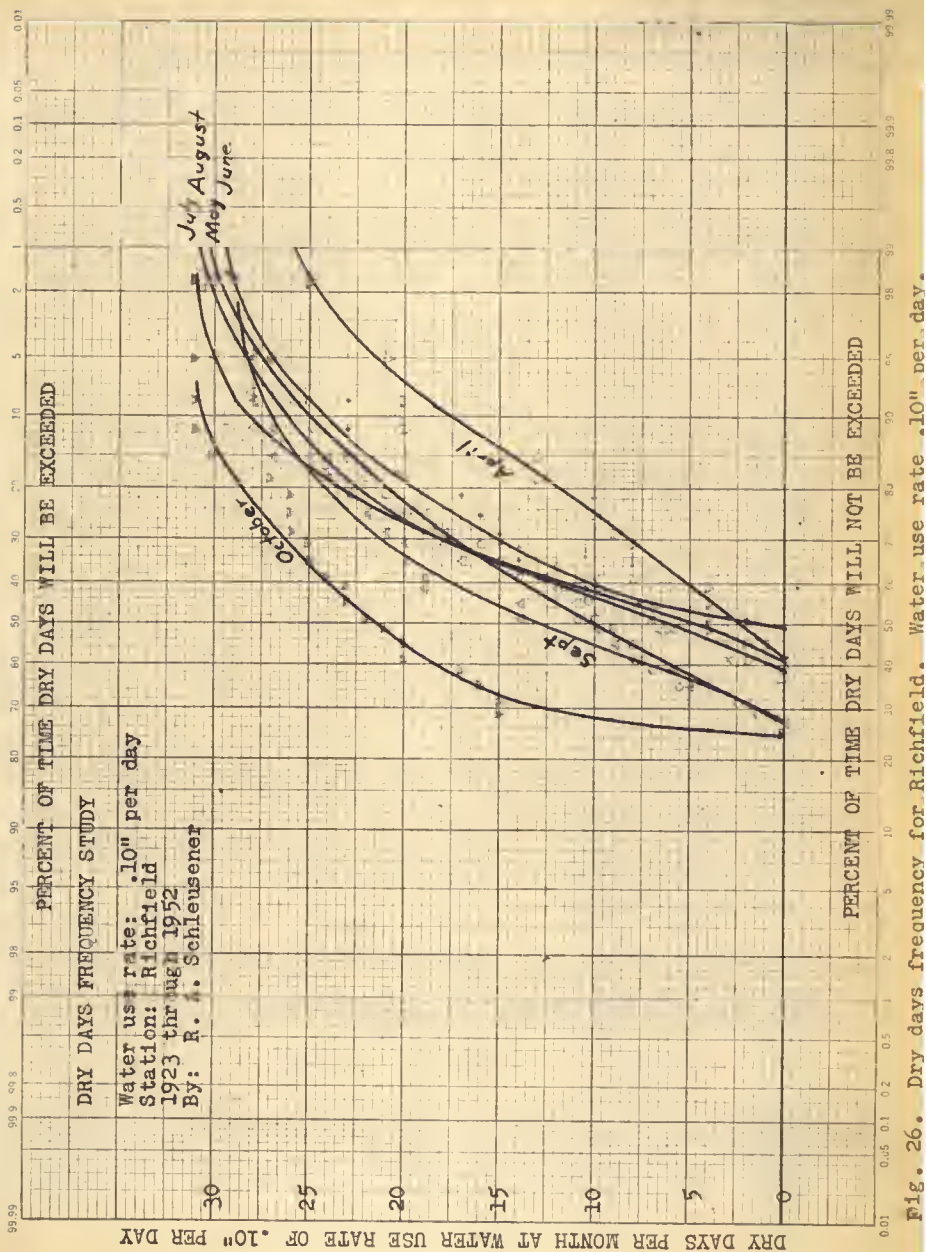Fig. 2. Dry days frequency for Cimmaron. Water use .10" per day.

Fig. 3. Dry days frequency for Cimmaron. Water use rate .20" per day.

DRY DAYS FREQUENCY STUDY

Water use rate: .20" per day.
Station: Cimmaron
1923 through 1952
By: R. A. Schleusener

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT WATER USE RATE OF .20" PER DAY

July
June
August
May

48

Fig. 4. Dry days frequency for Cimmaron. Water use rate .30" per day.

Fig. 5. Dry days frequency for Dodge City. Water use rate .05" per day.

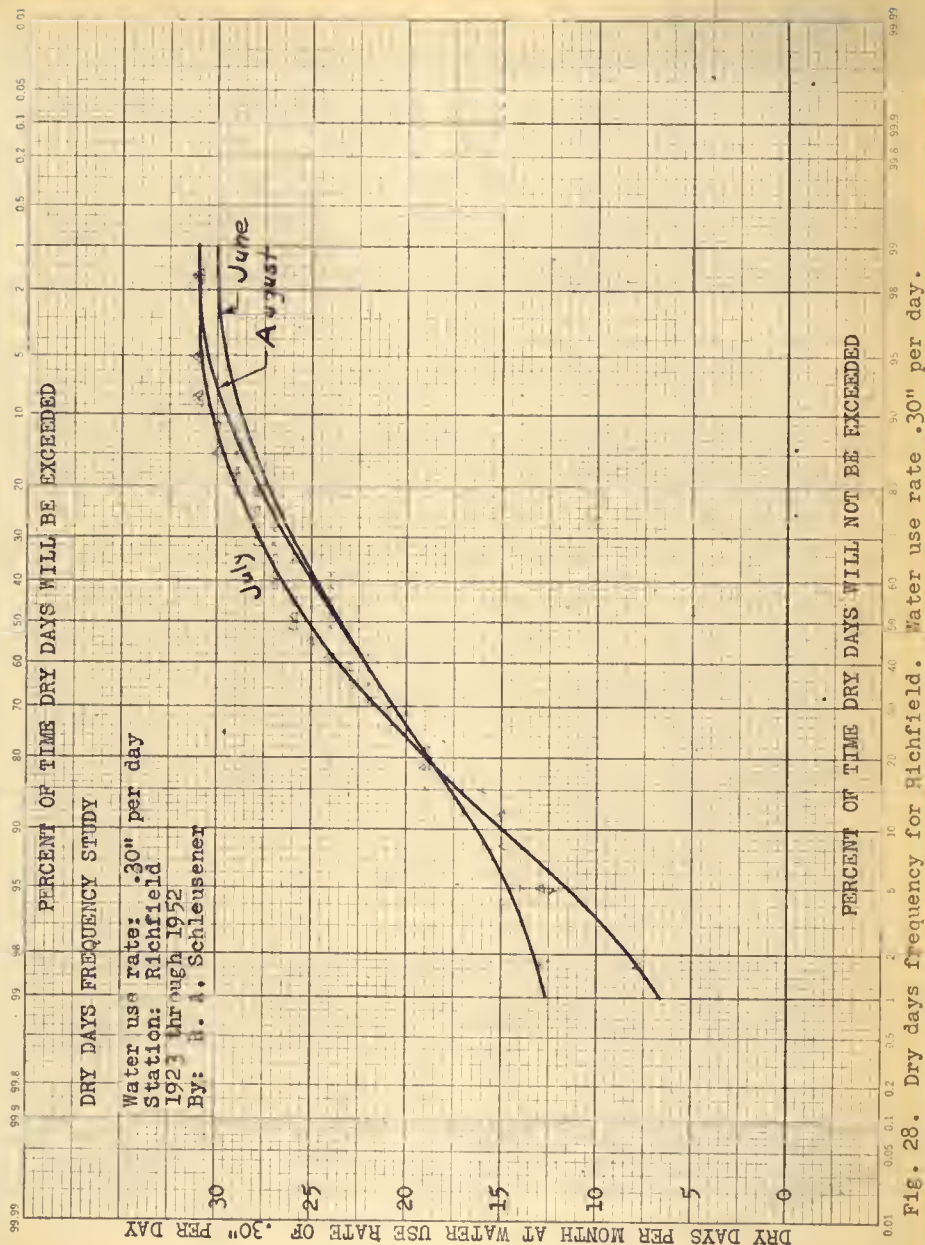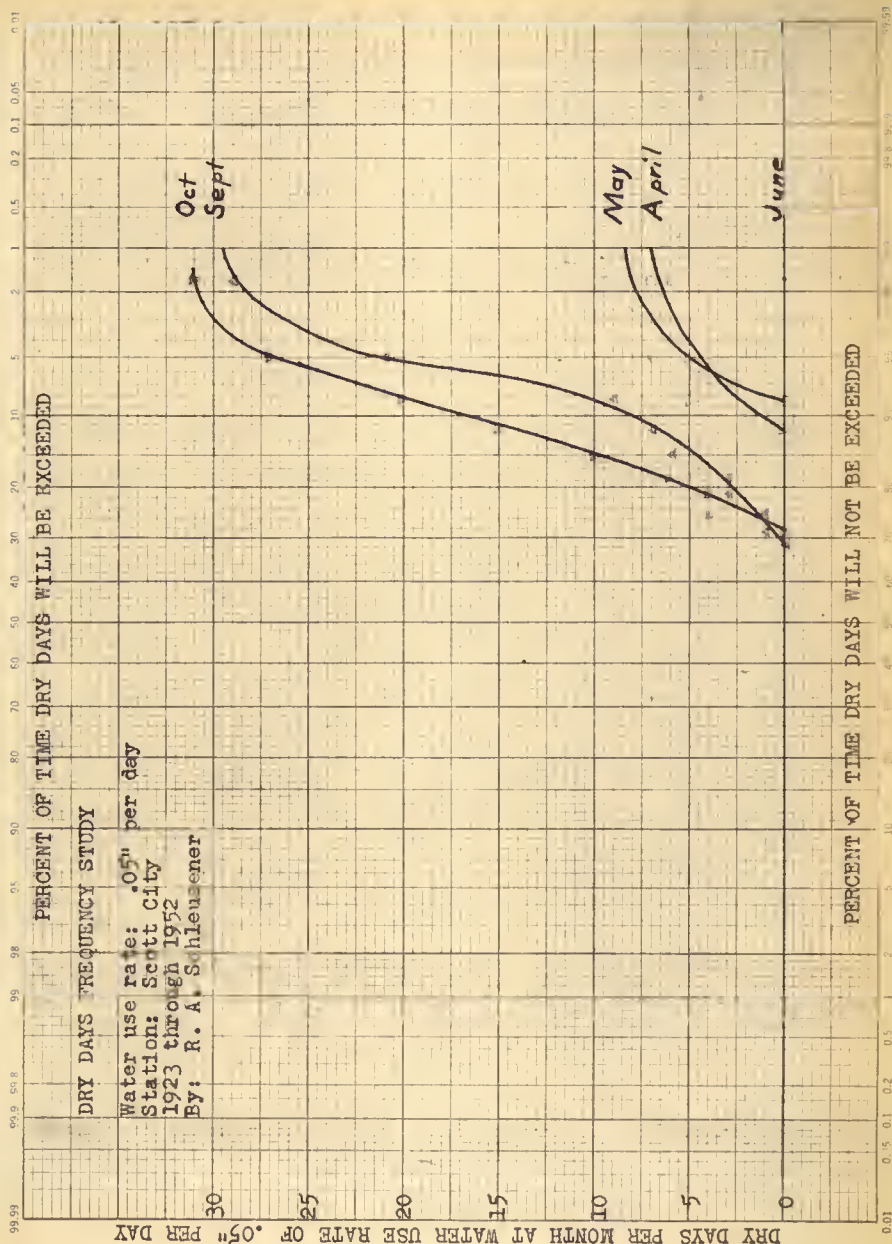Fig. 6. Dry days frequency for Dodge City. Water use rate .10" per day.

Fig. 7. Dry days frequency for Dodge City. Water use rate .20" per day.

Fig. 8. Dry days frequency for Dodge City. Water use rate .30" per day.
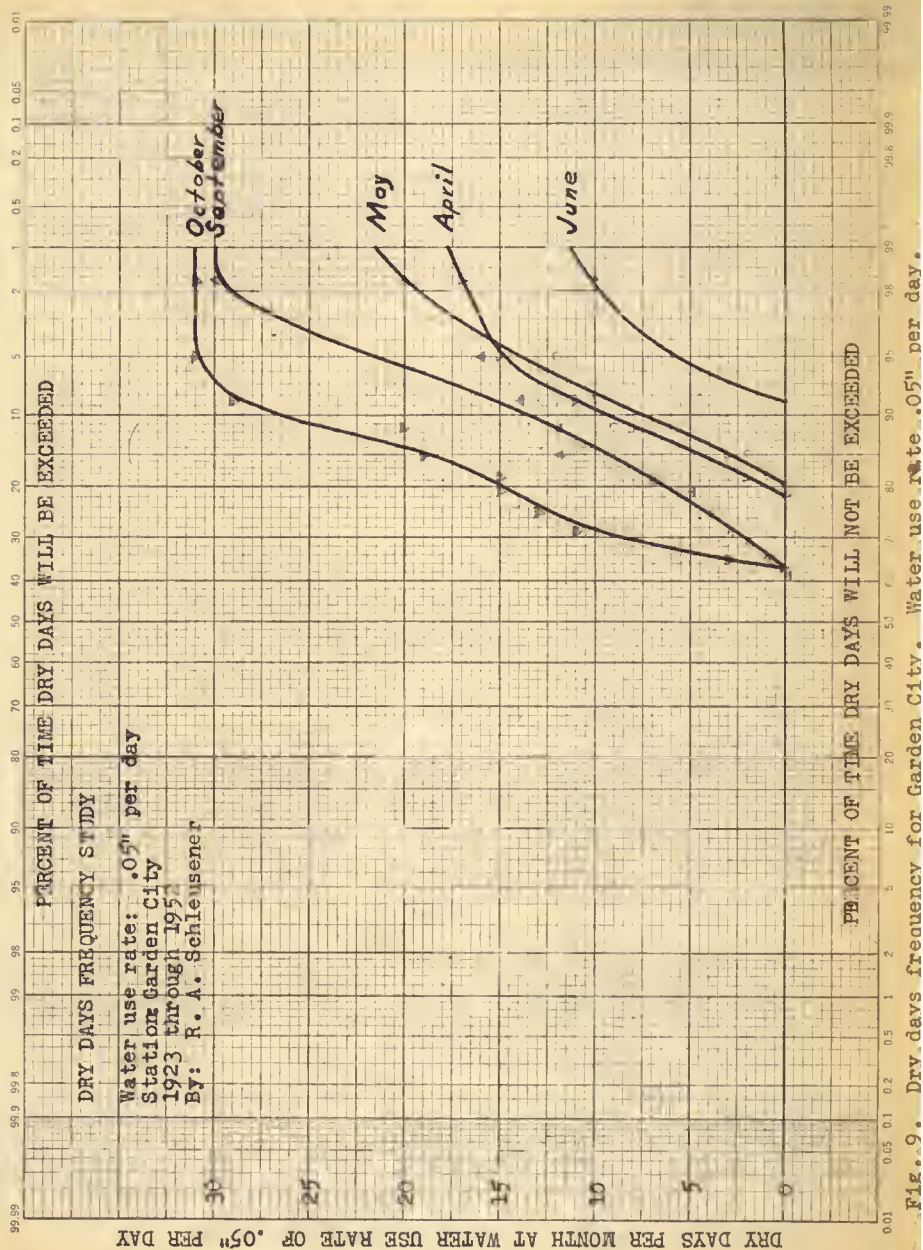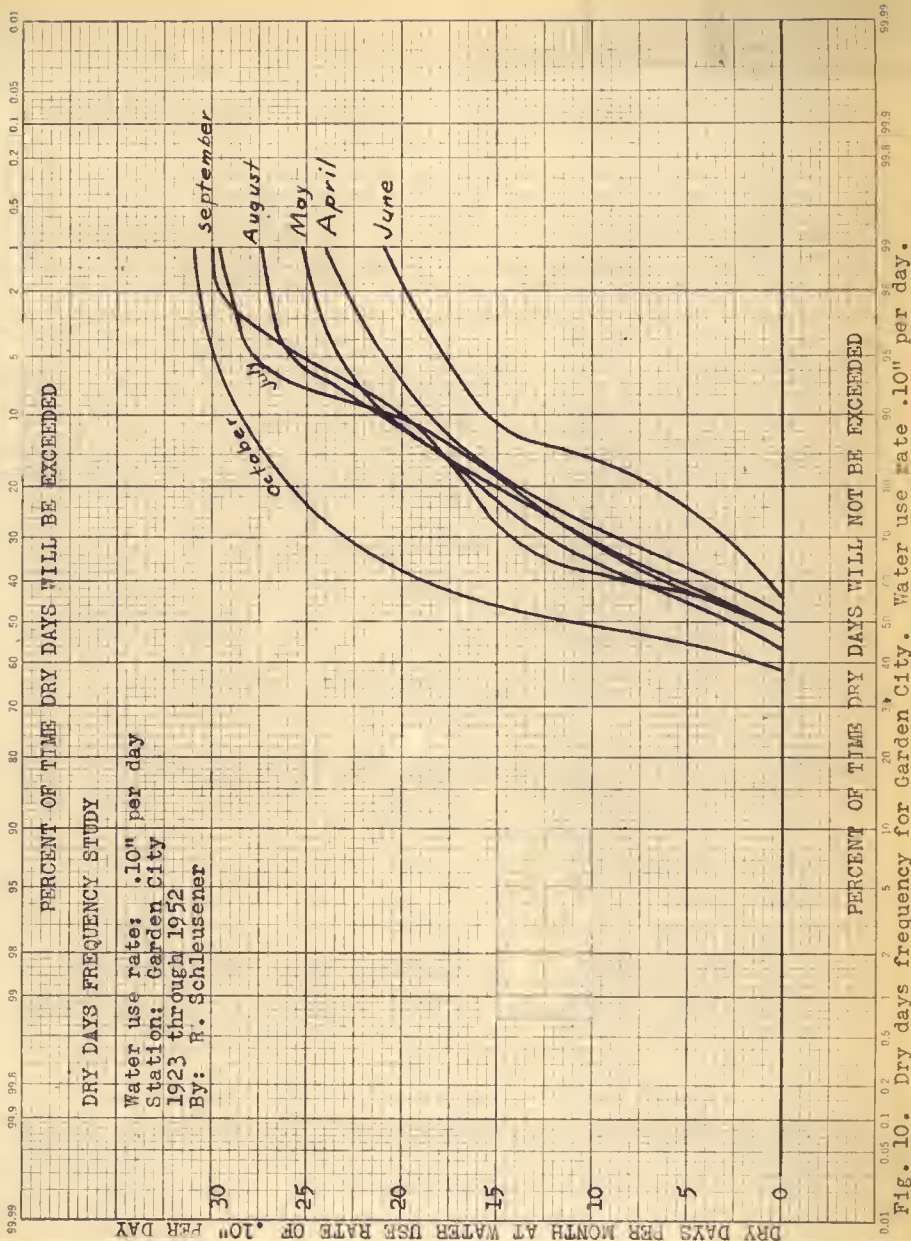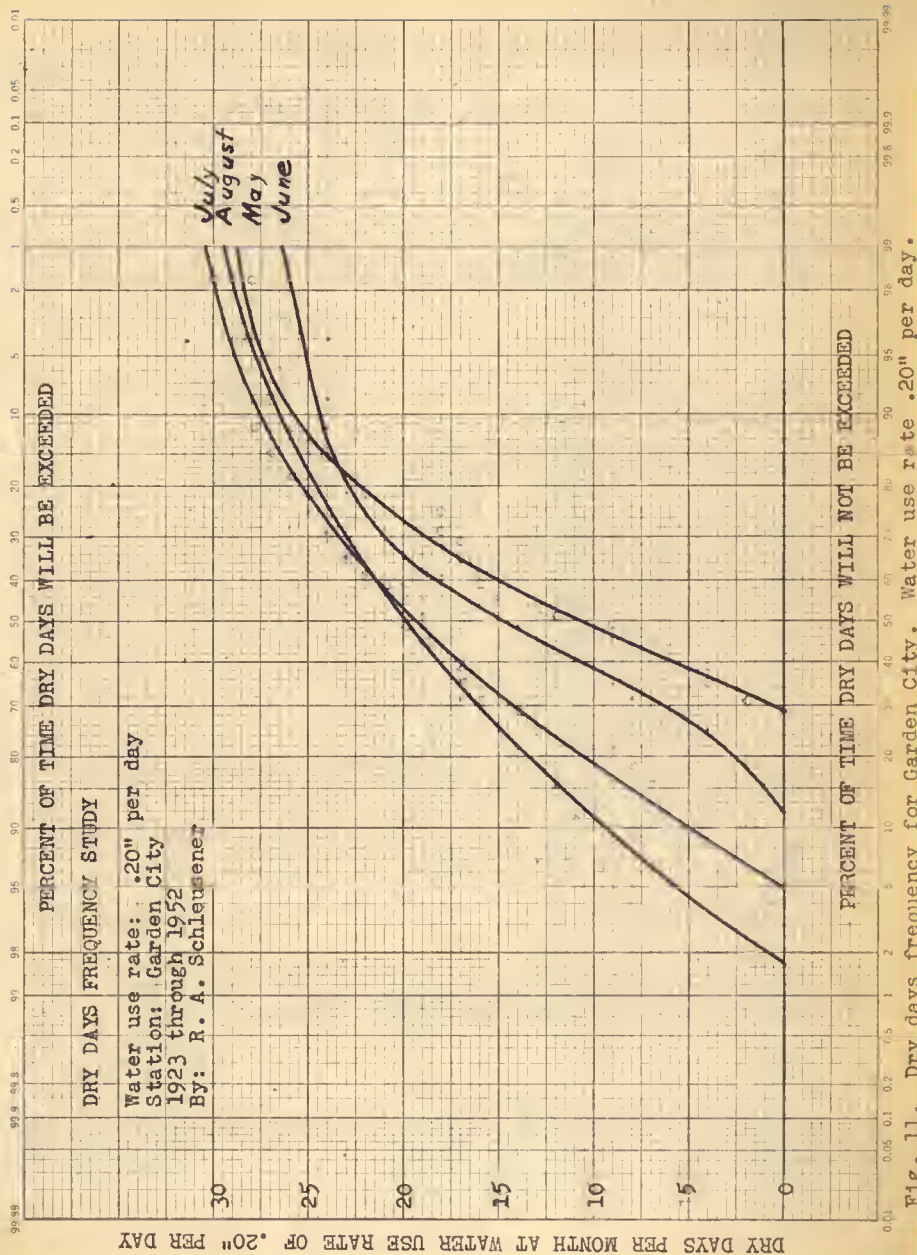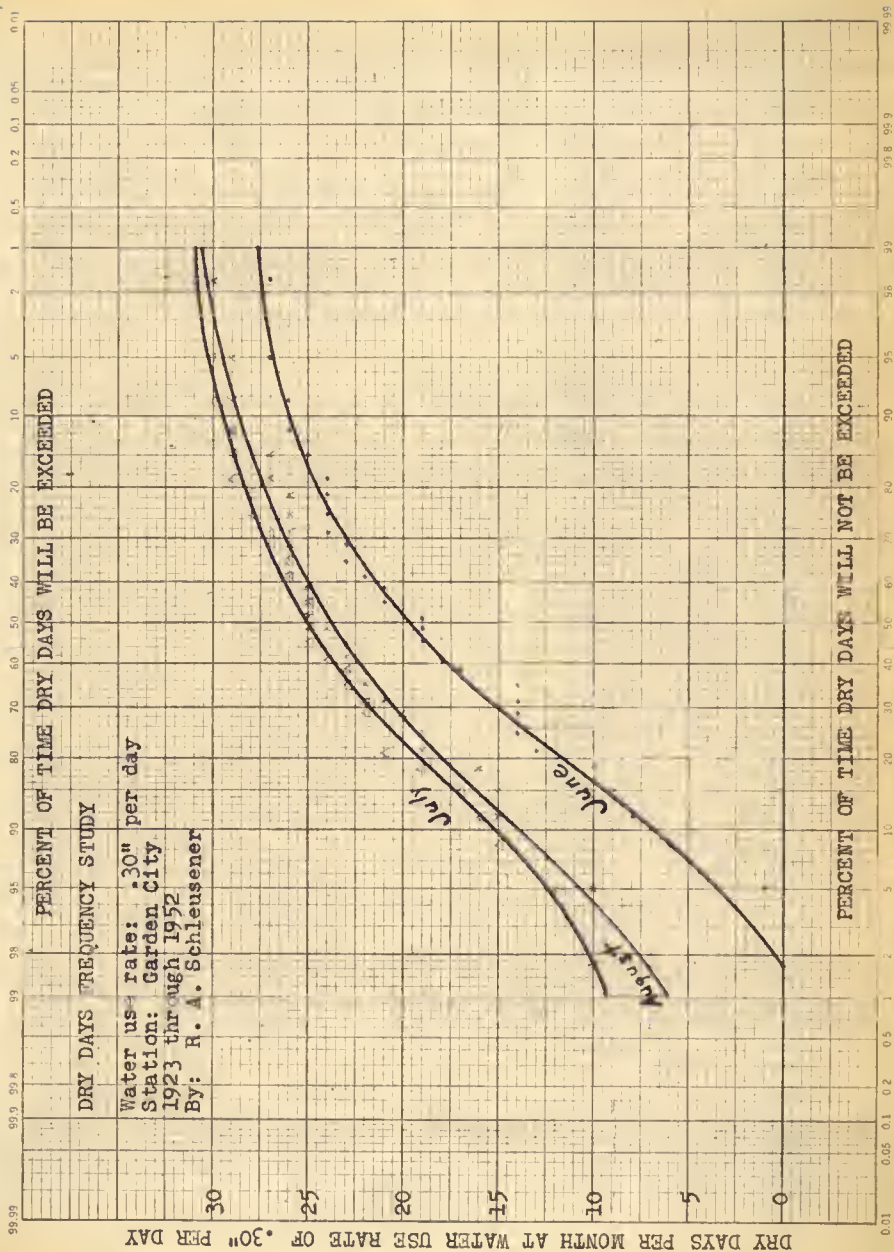
Fig. 9. Dry days frequency for Garden City. Water use rate .05" per day.

Fig. 10. Dry days frequency for Garden City. Water use rate .10" per day.

Fig. 11. Dry days frequency for Garden City. Water use rate .20" per day.

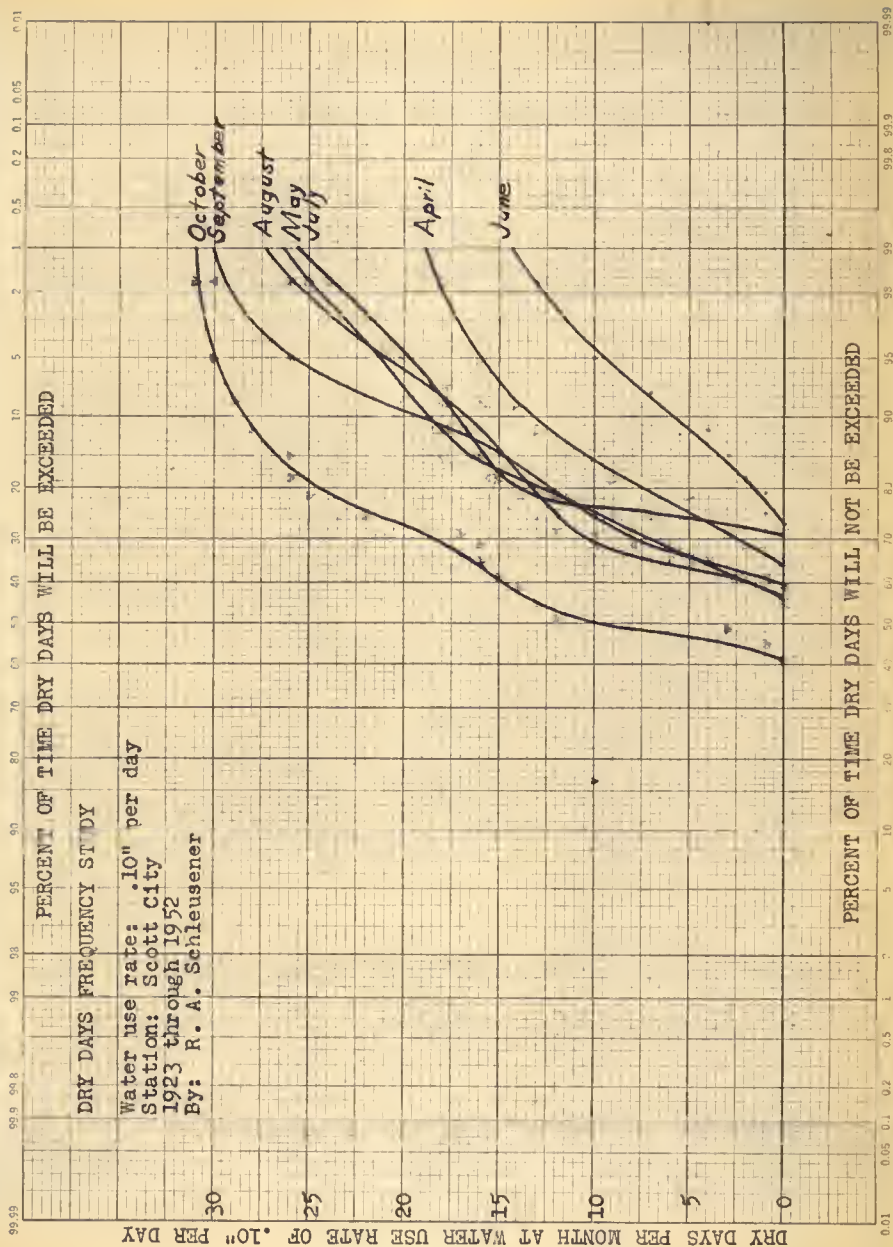Fig. 12. Dry days frequency for Garden City. Water use rate .30" per day.
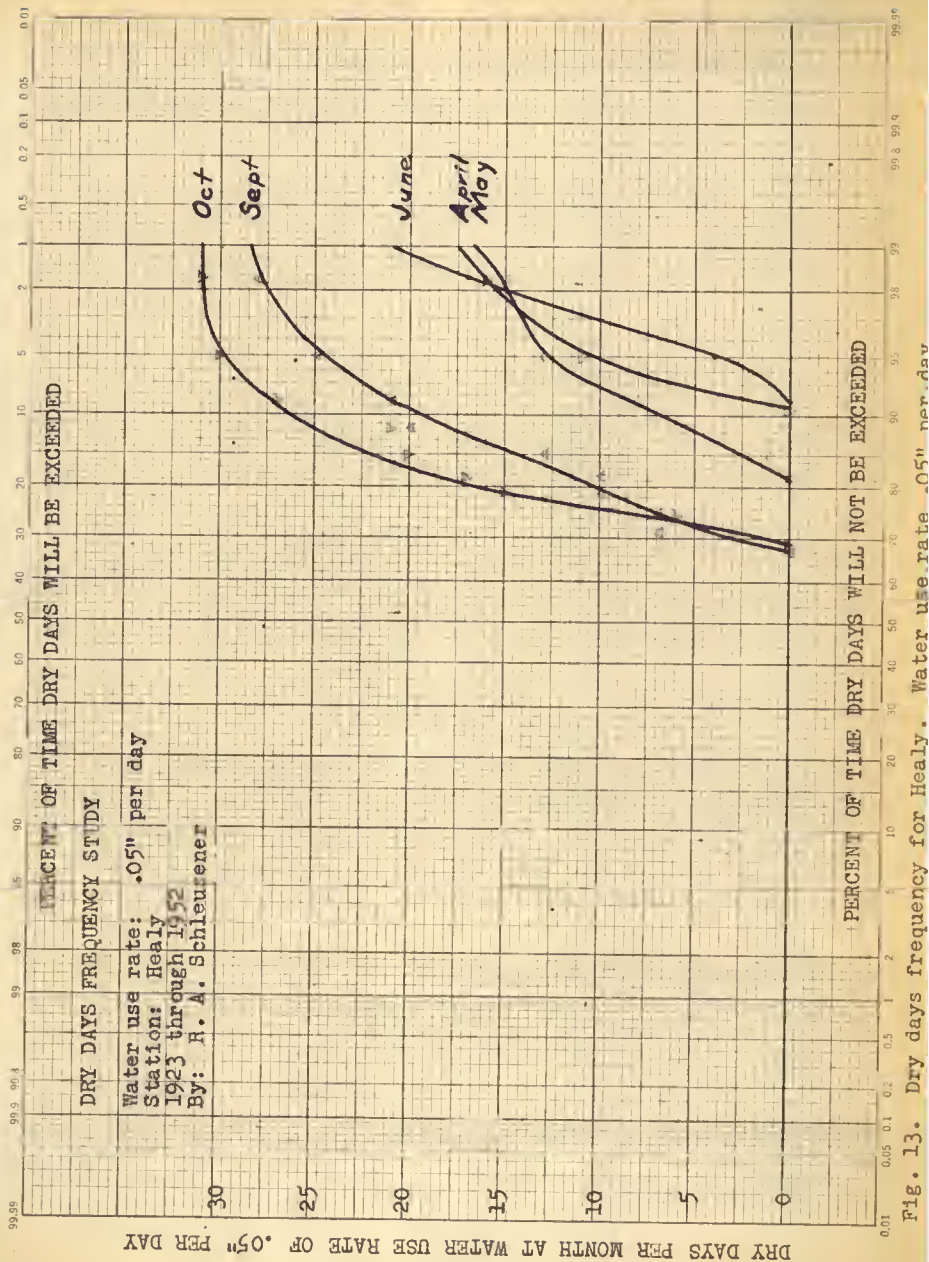
Fig. 13. Dry days frequency for Healy. Water use rate .05" per day

DRY DAYS FREQUENCY STUDY

Water use rate: .10" per day
Station: Healy
1923 through 1952
By: R. A. Schleusener

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT WATER USE RATE OF .10" PER DAY

October
September
August
July
May
April
June

Fig. 14. Dry days frequency for Healy. Water use rate .10" per day.
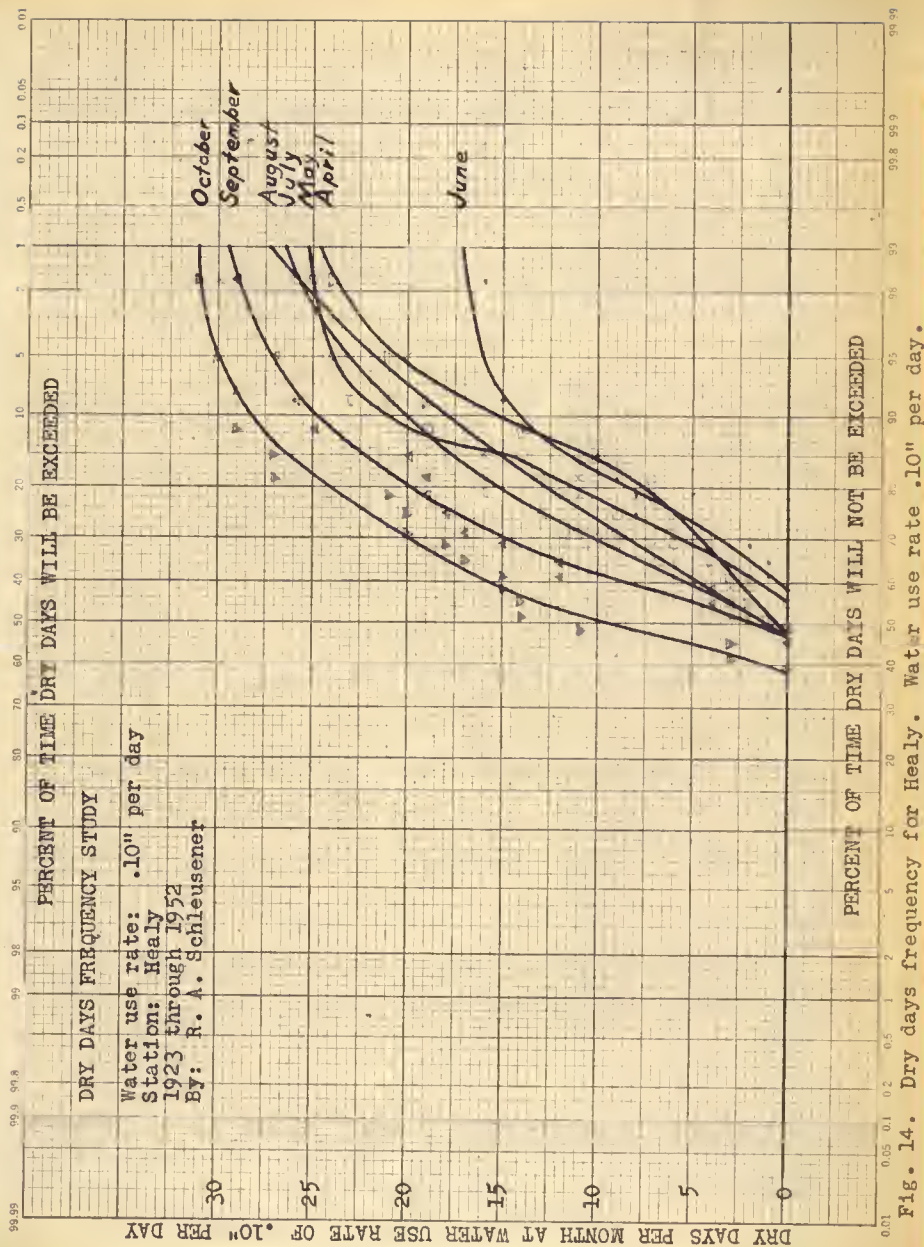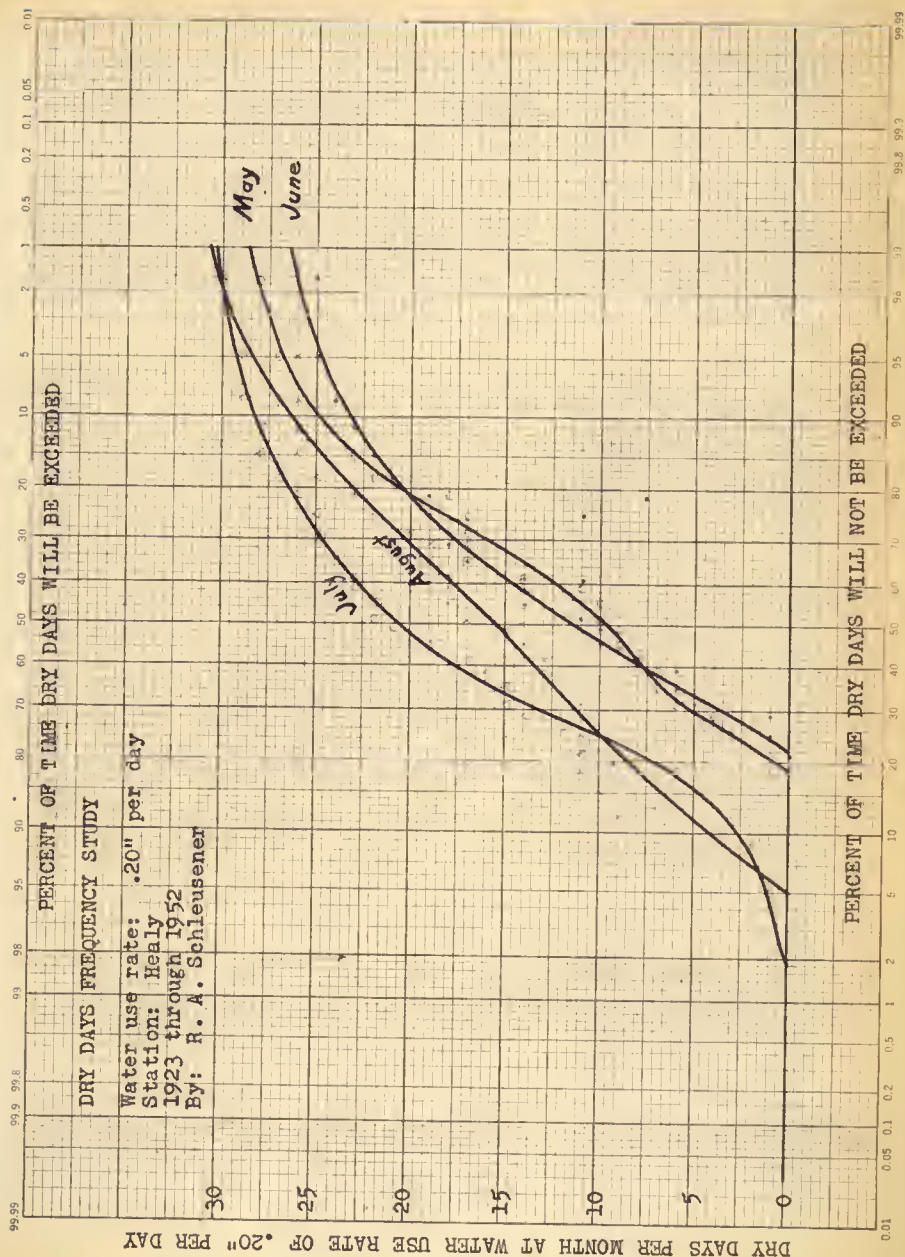
Fig. 15. Dry days frequency for Healy. Water use rate .20" per day.

61

Fig. 16. Dry days frequency for Healy. Water use rate .30" per day.

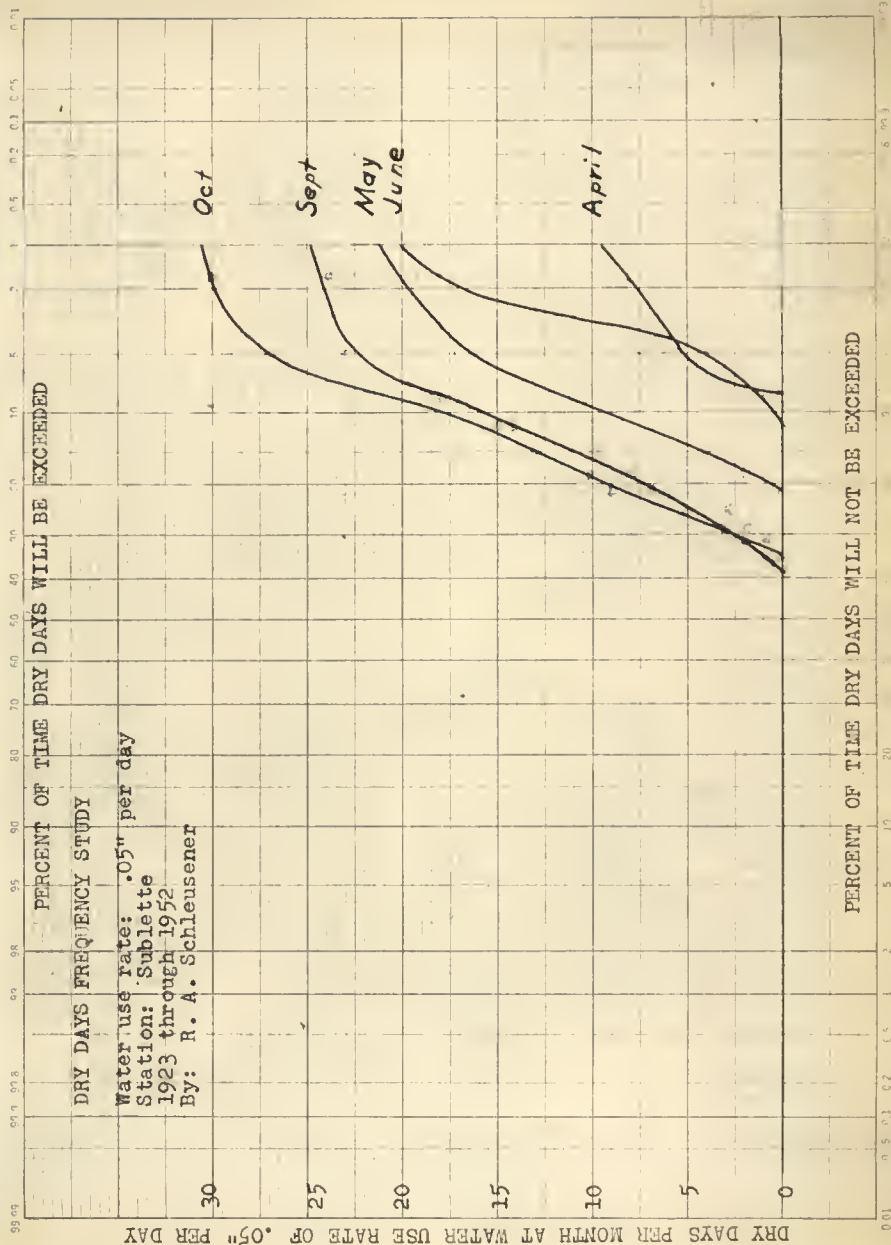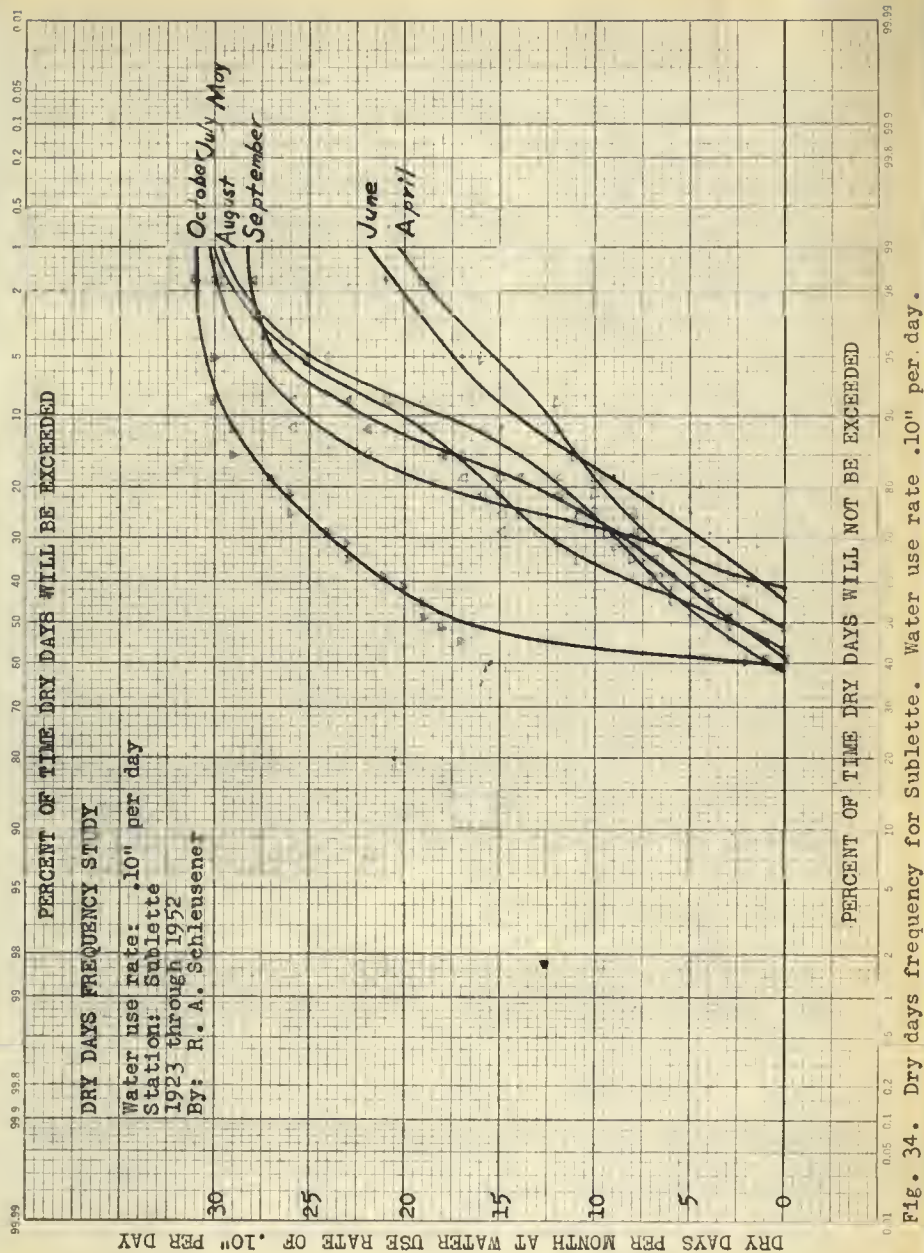Fig. 17 - Dry days frequency for Johnson. Water use rate .05" per day.

63


Fig. 18. Dry days frequency for Johnson. Water use rate .10" per day.
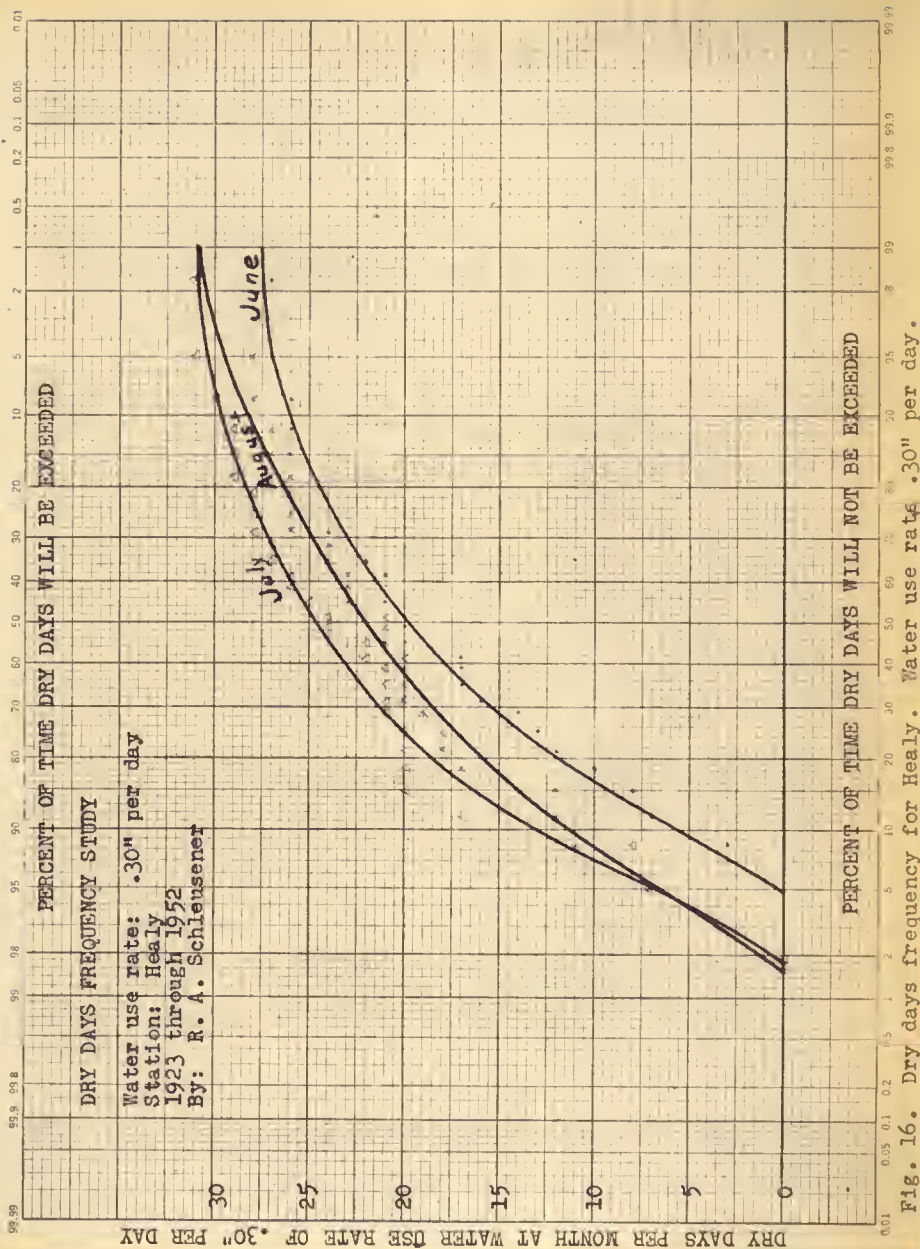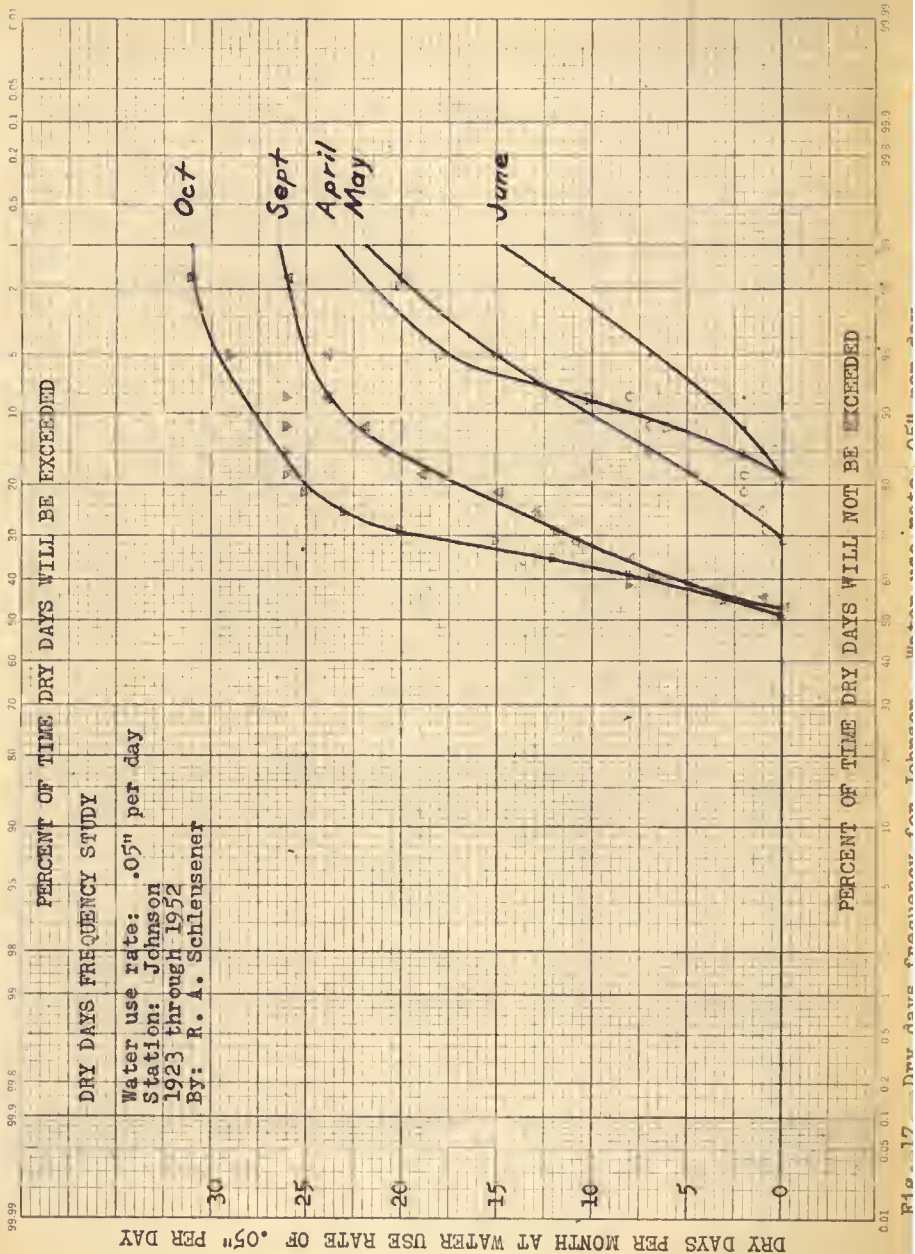
Fig. 19. Dry days frequency for Johnson. Water use rate .20" per day.

Fig. 20. Dry days frequency for Johnson. Water use rate .30" per day.
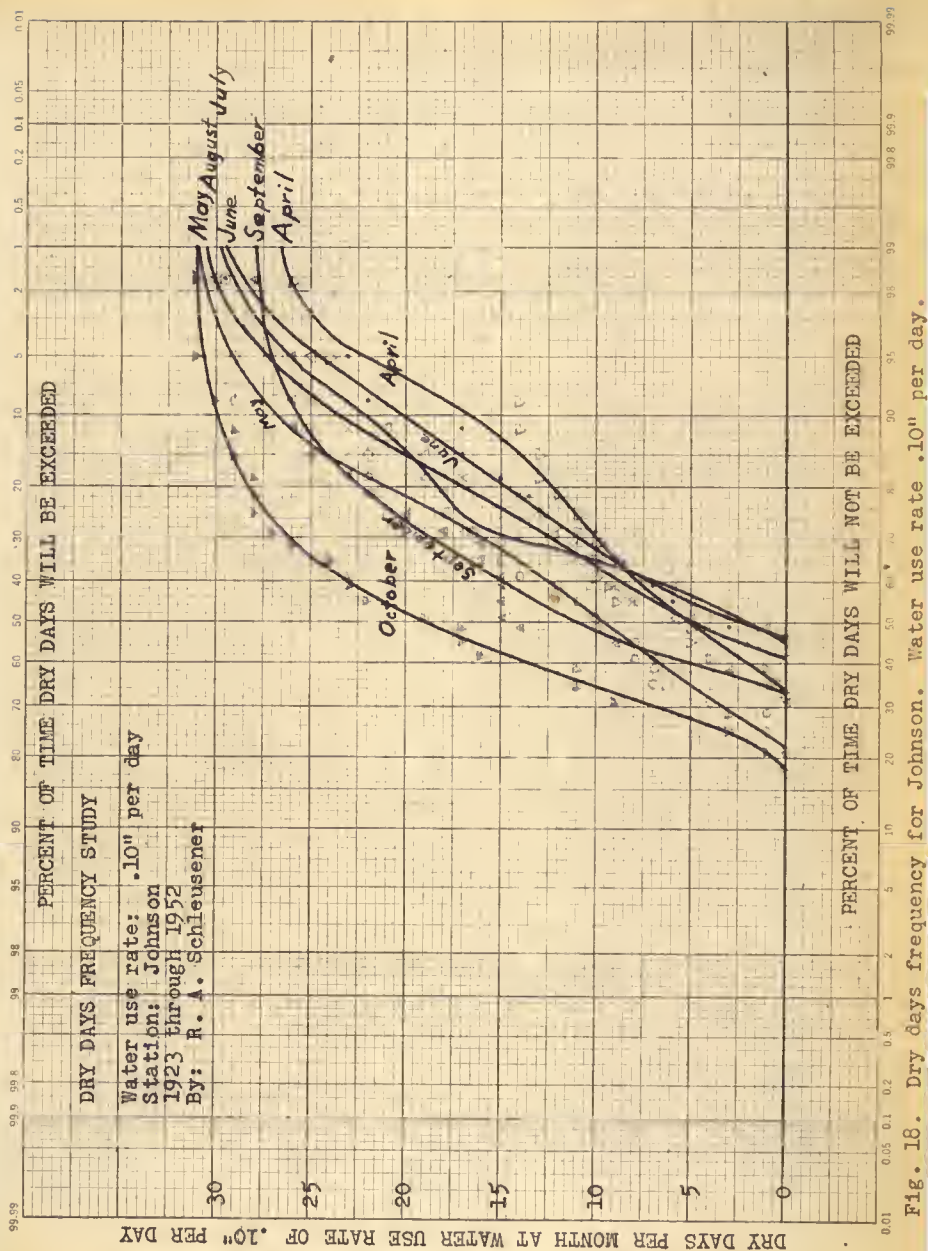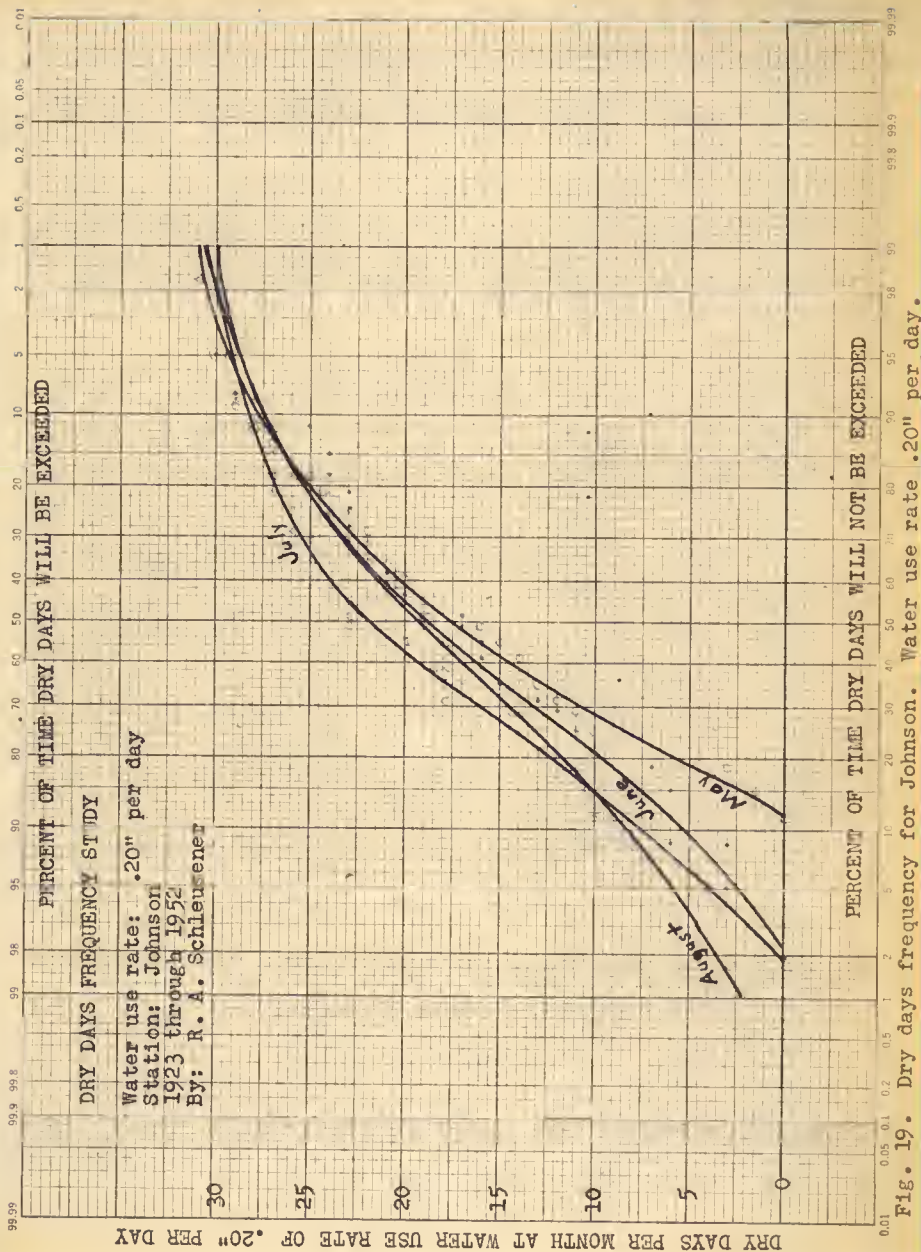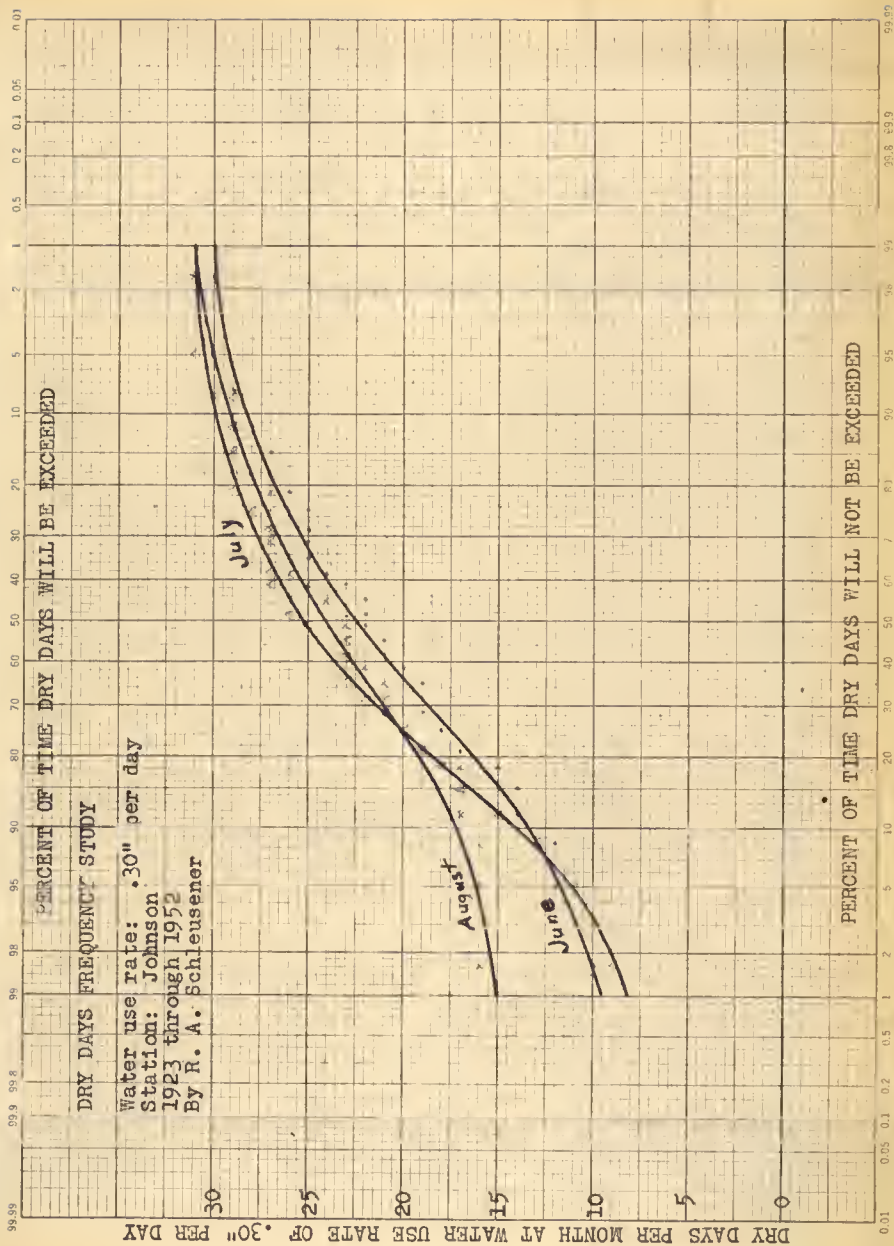
Fig. 21. Dry days frequency for Liberal. Water use rate .05" per day.
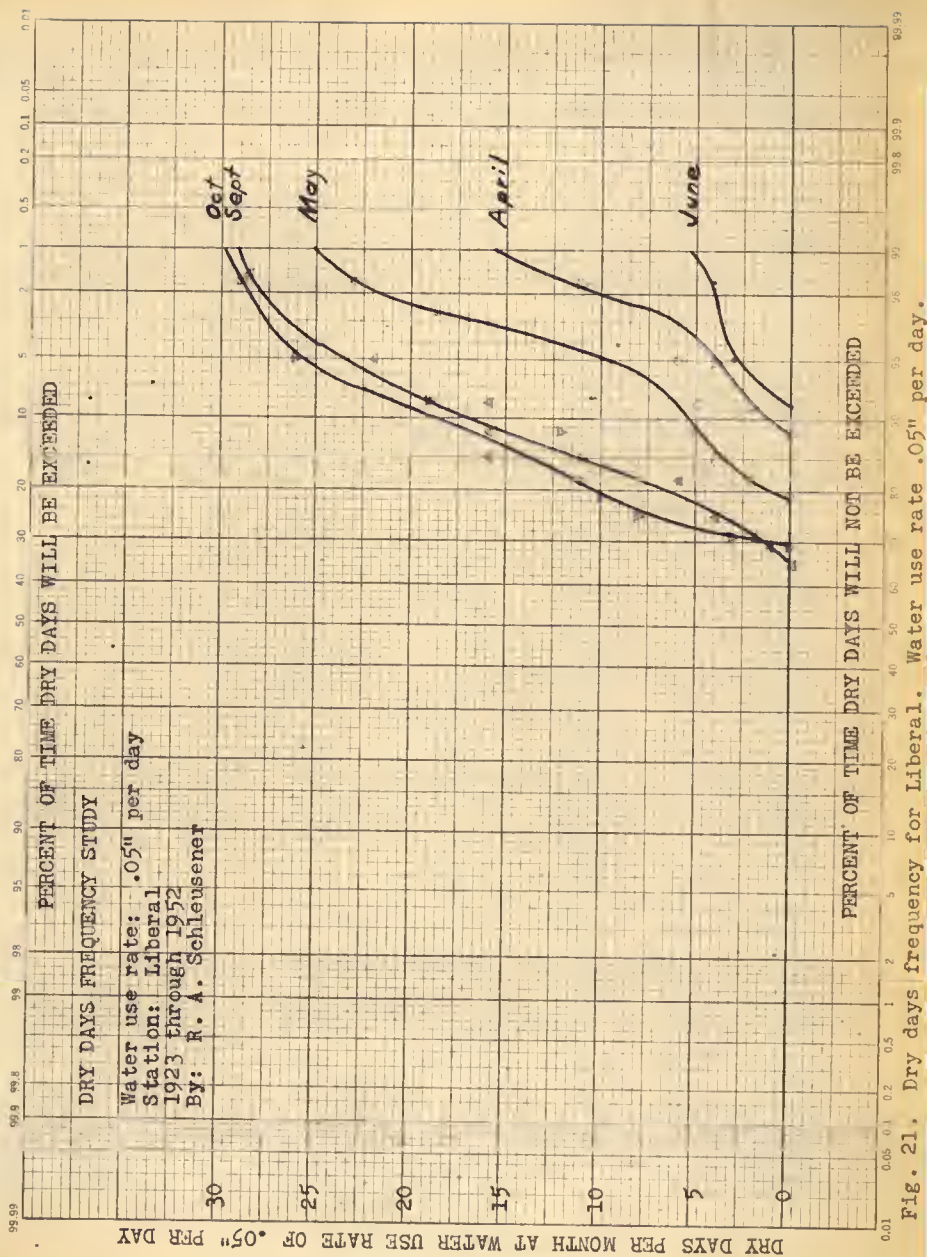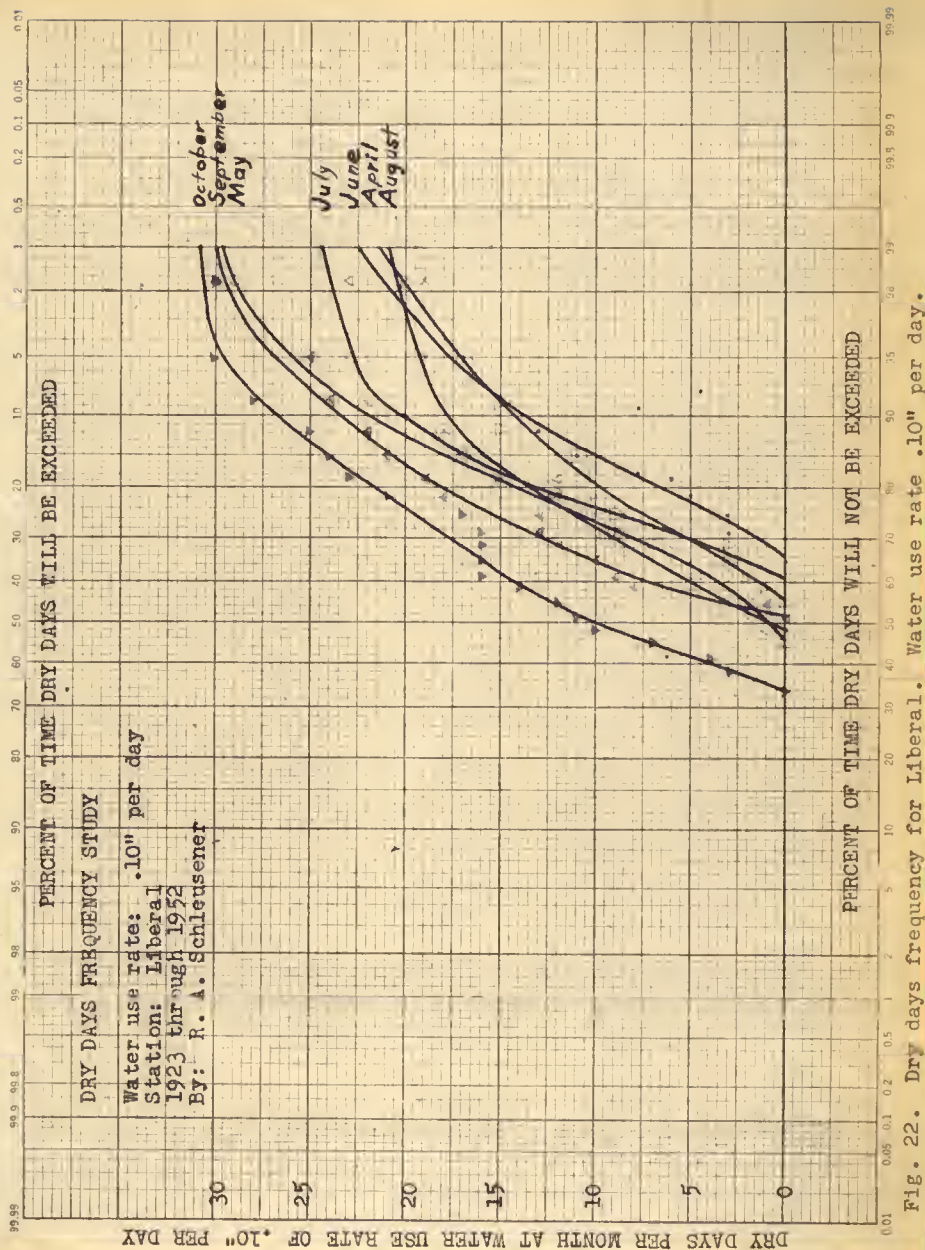
Fig. 22. Dry days frequency for Liberal. Water use rate .10" per day.
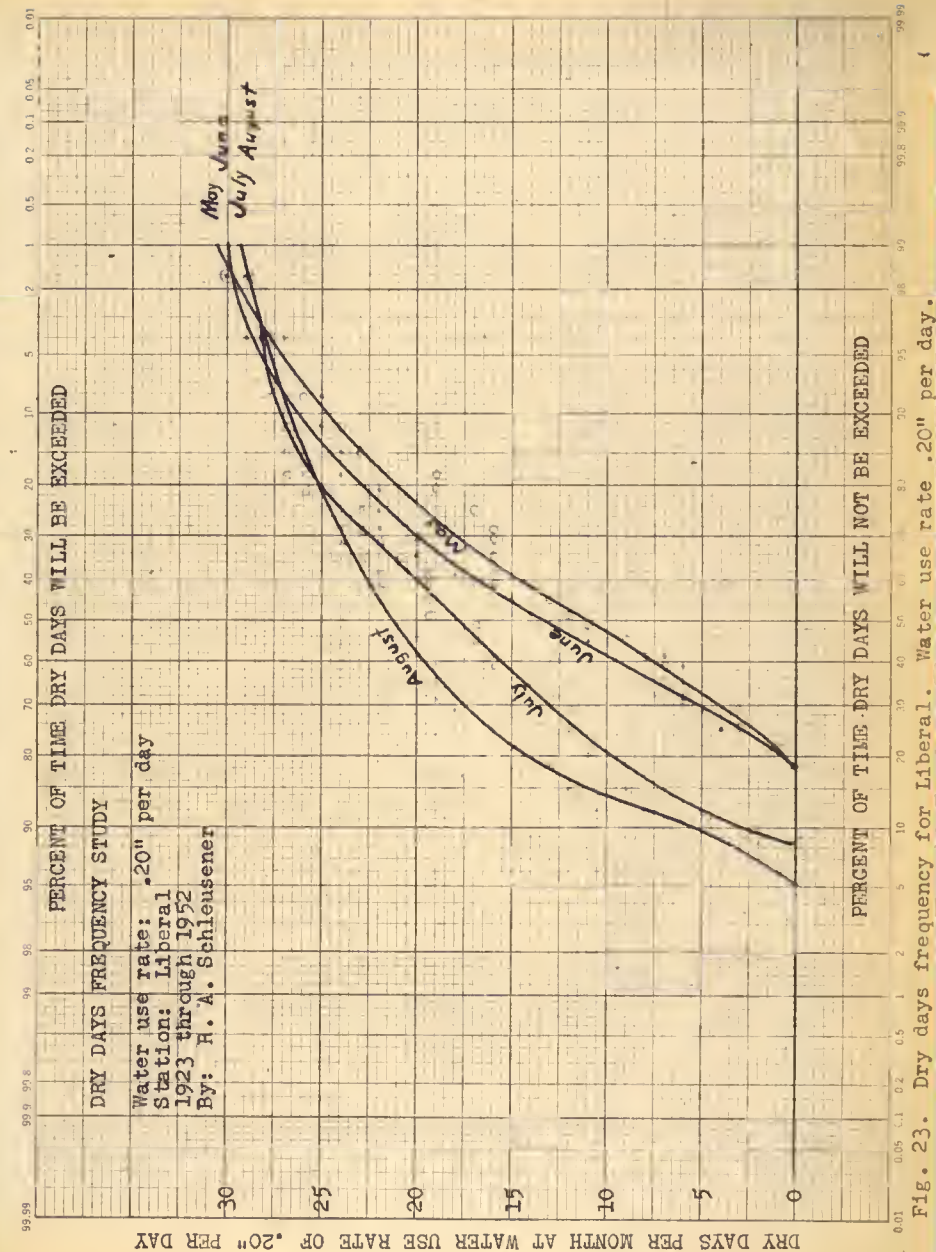
Fig. 23. Dry days frequency for Liberal. Water use rate .20" per day.

Fig. 24. Dry days frequency for Liberal. Water use rate .30" per day.

Fig. 25. Dry days frequency for Richfield. Water use rate .05" per day.

71

Fig. 26. Dry days frequency for Richfield. Water use rate .10" per day.
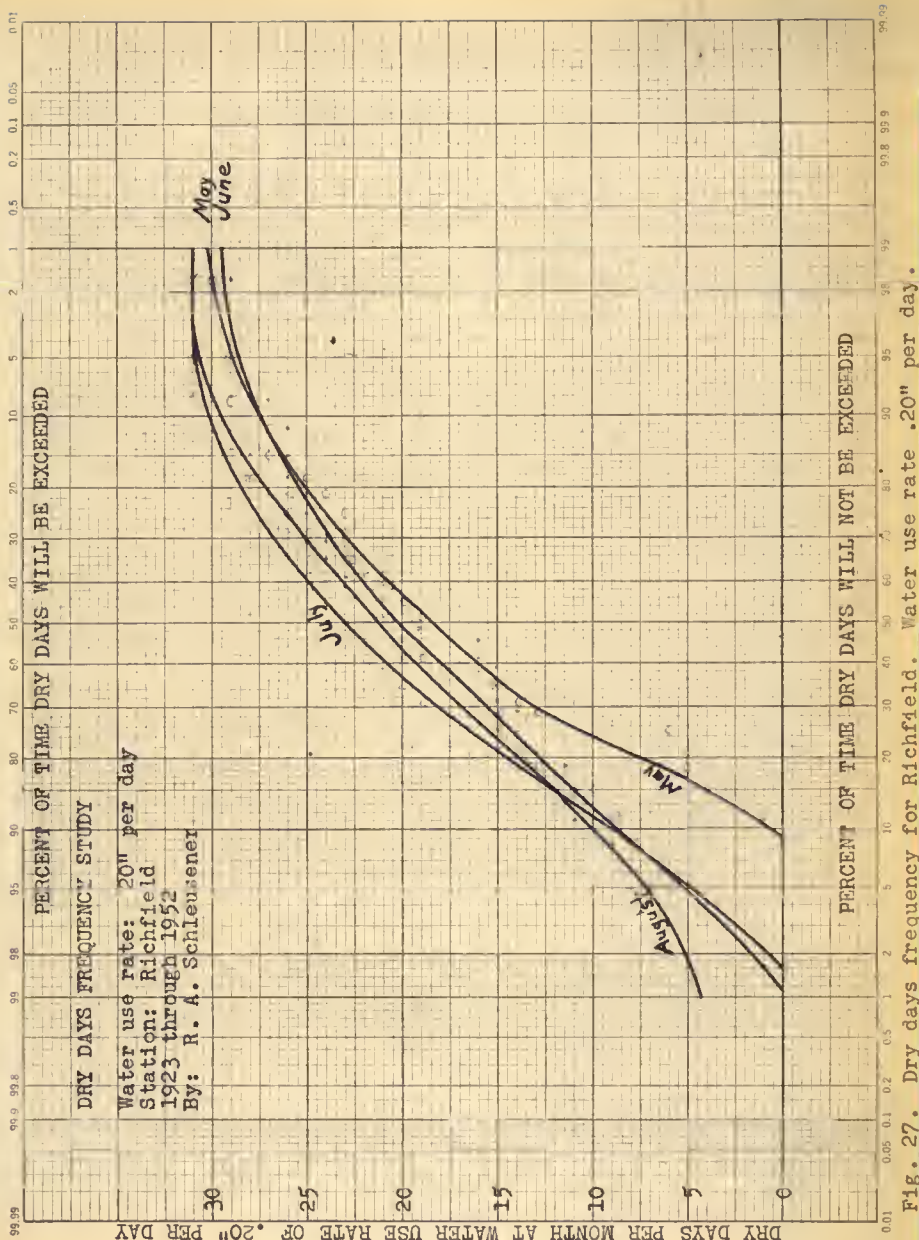
Fig. 27. Dry days frequency for Richfield. Water use rate .20" per day.

Fig. 28. Dry days frequency for Richfield. Water use rate .30" per day.

Fig. 29. Dry days frequency for Scott City. Water use rate .05" per day.

Fig. 30.. Dry days frequency for Scott City. Water use rate .10" per day.

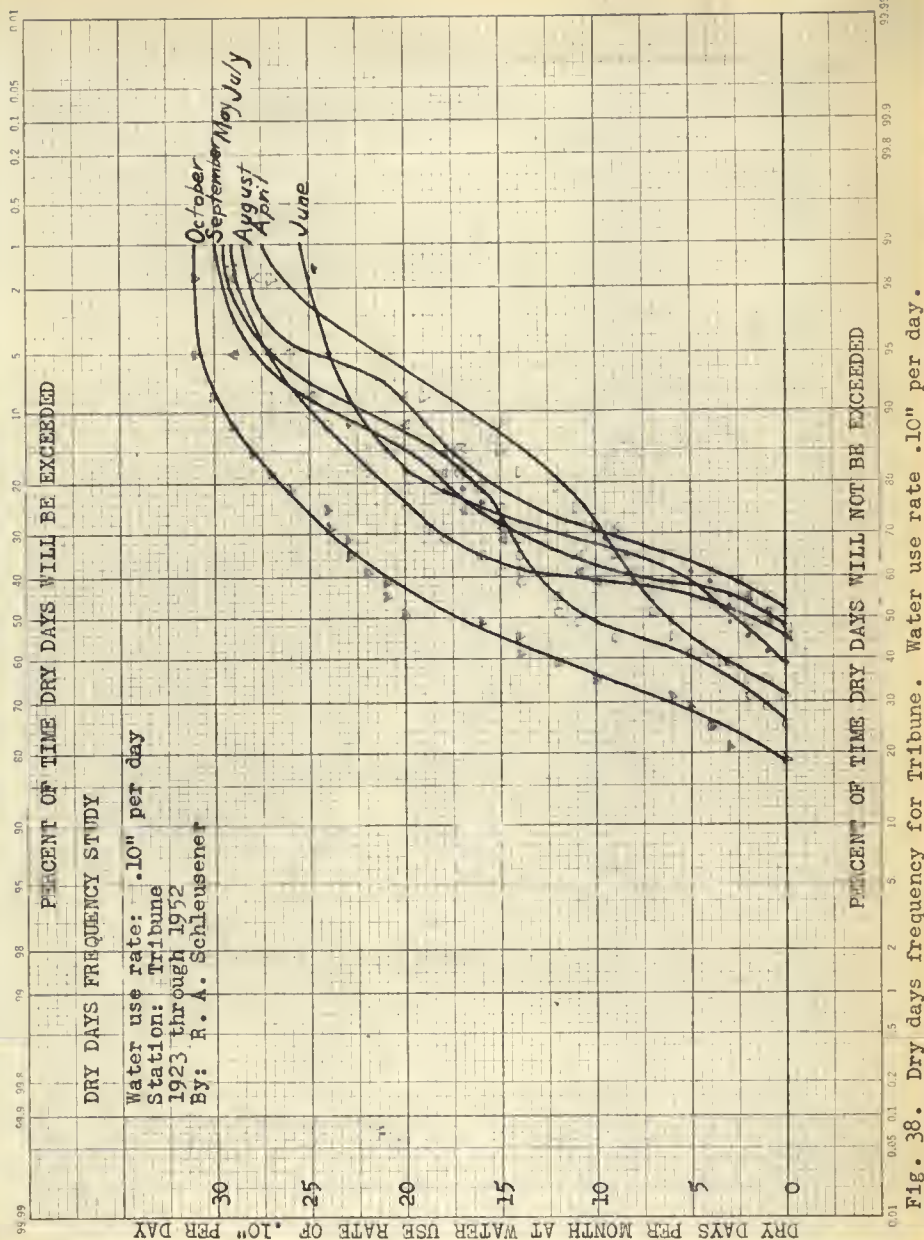Fig. 31. Dry days frequency for Scott City. Water use rate .20" per day.

Fig. 32. Dry days frequency for Scott City. Water use rate .30" per day.

Fig. 33. Dry days frequency for Sublette. Water use rate .05" per day.

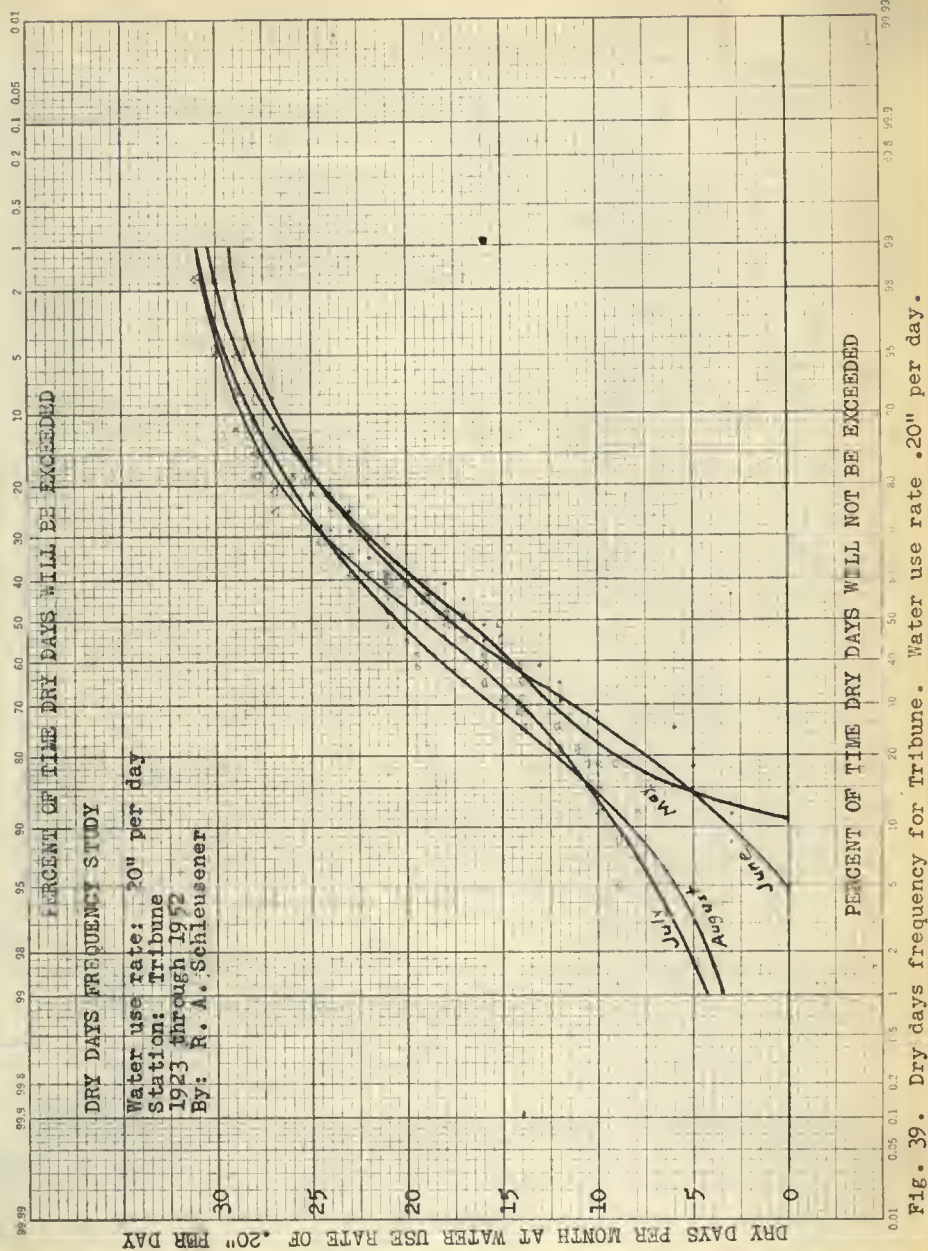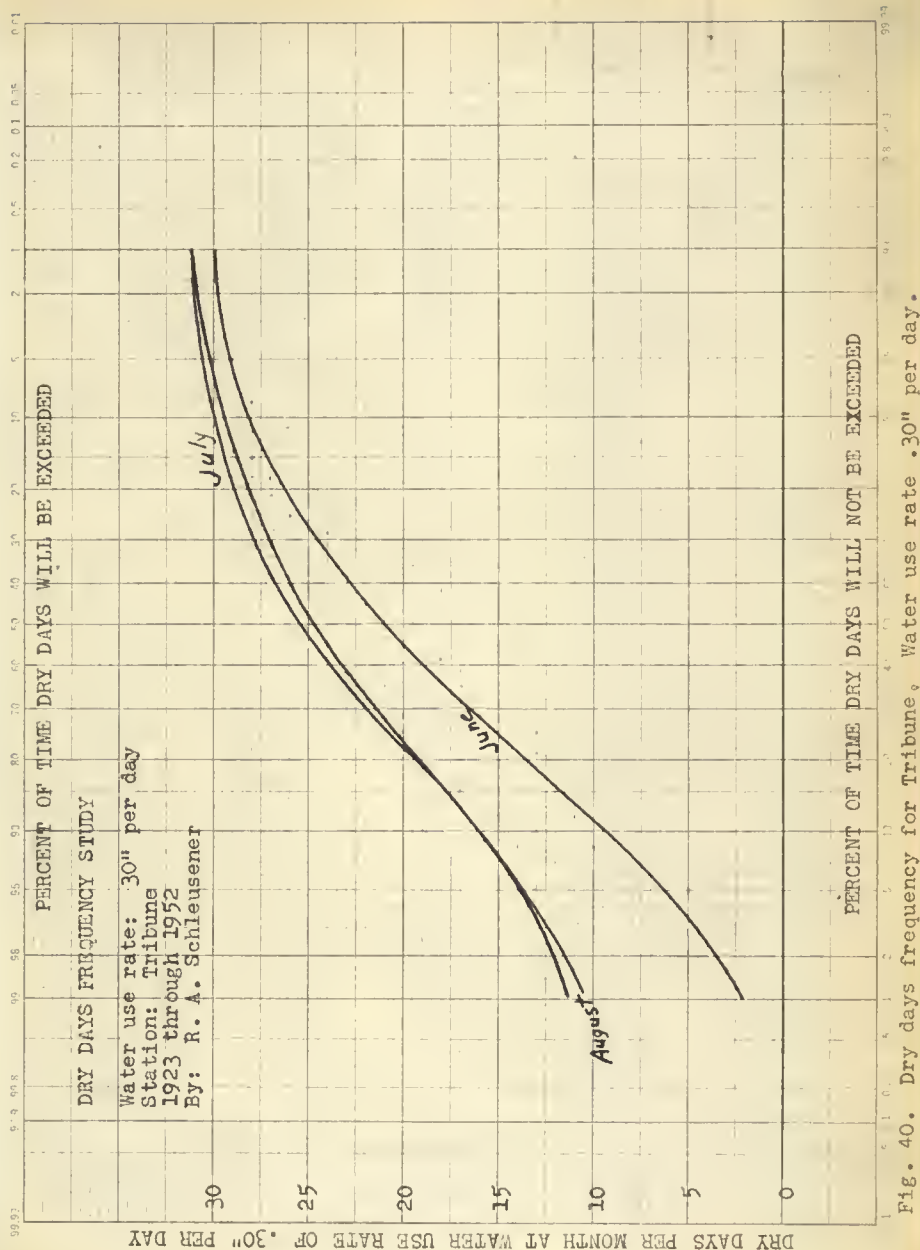Fig. 34. Dry days frequency for Sublette. Water use rate .10" per day.

Fig. 35. Dry days frequency for Sublette. Water use rate .20" per day
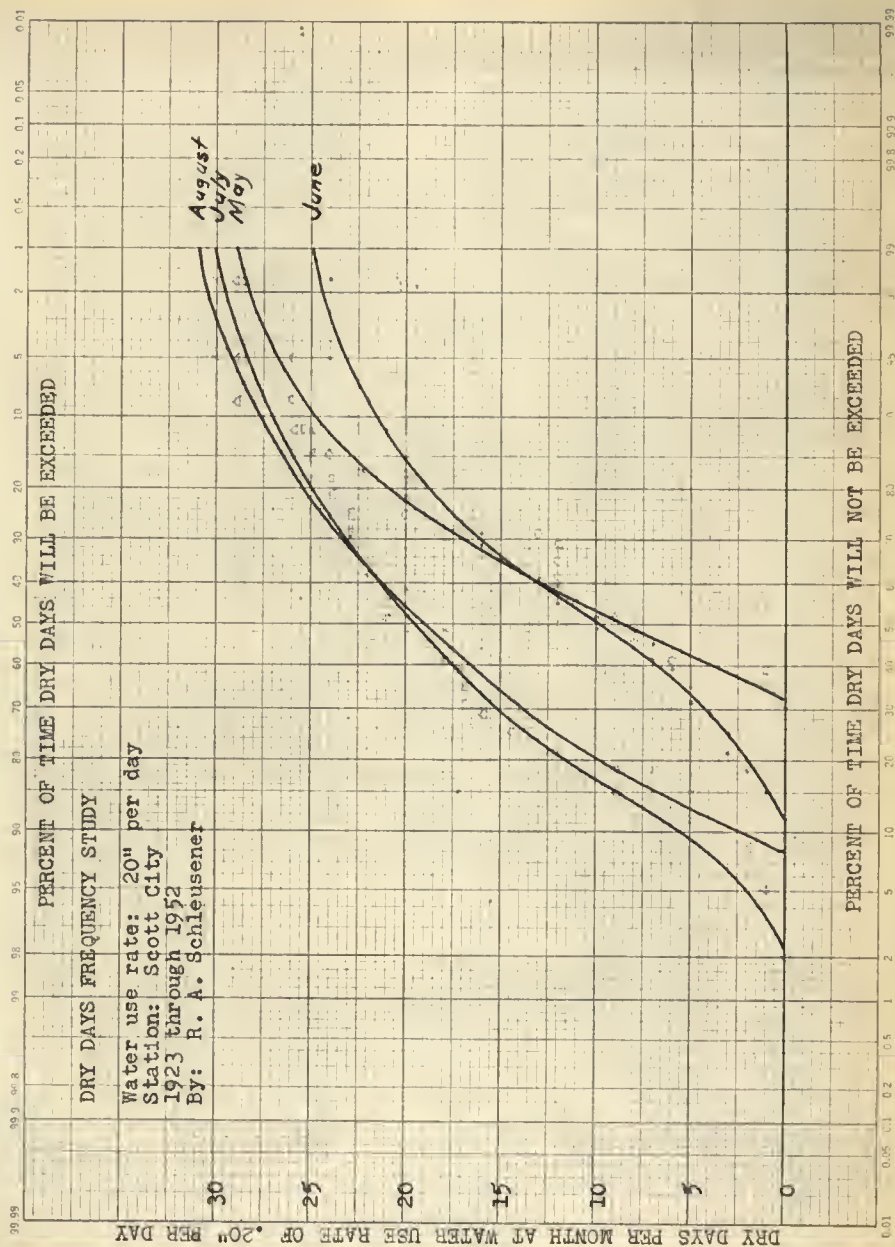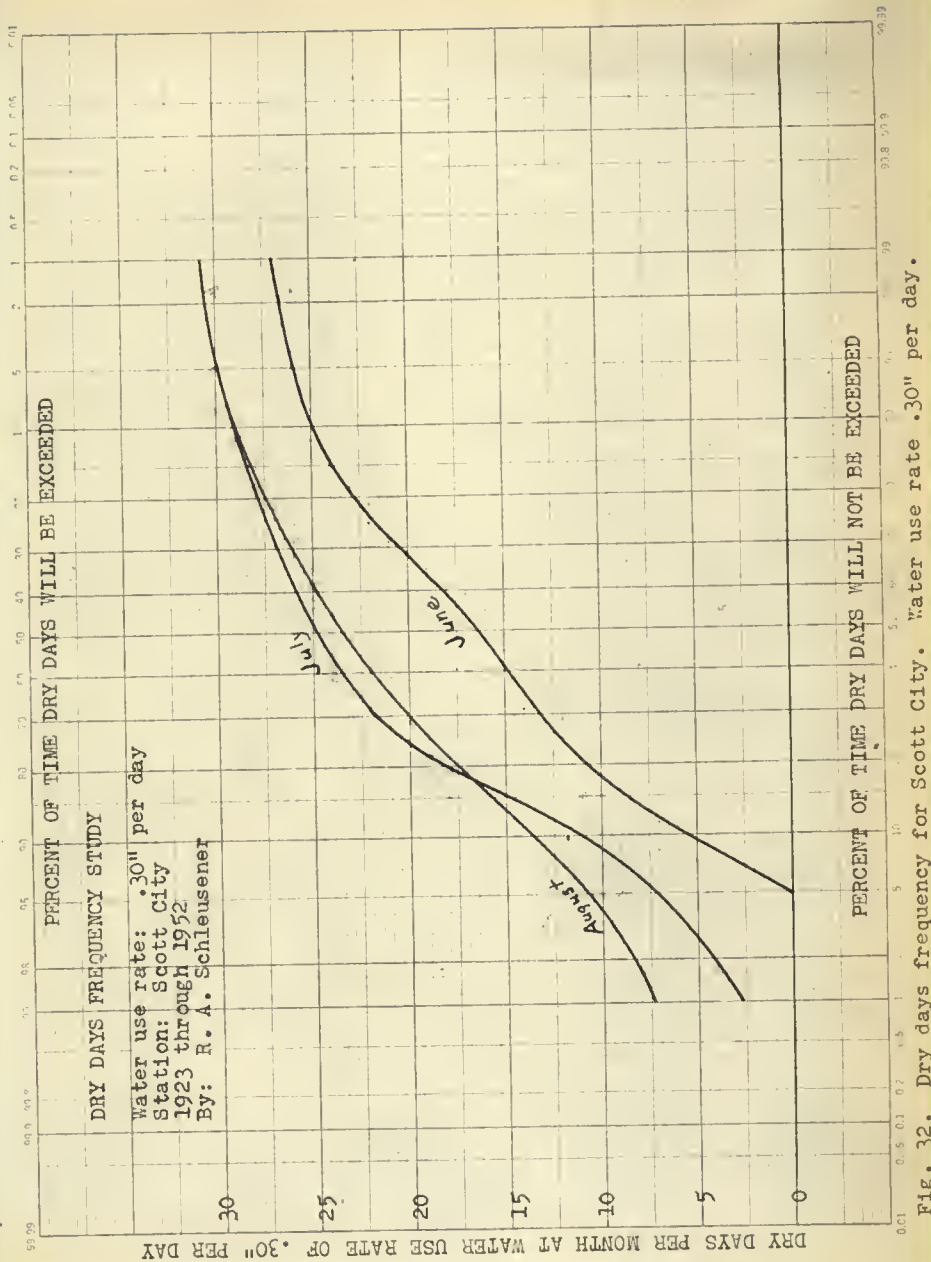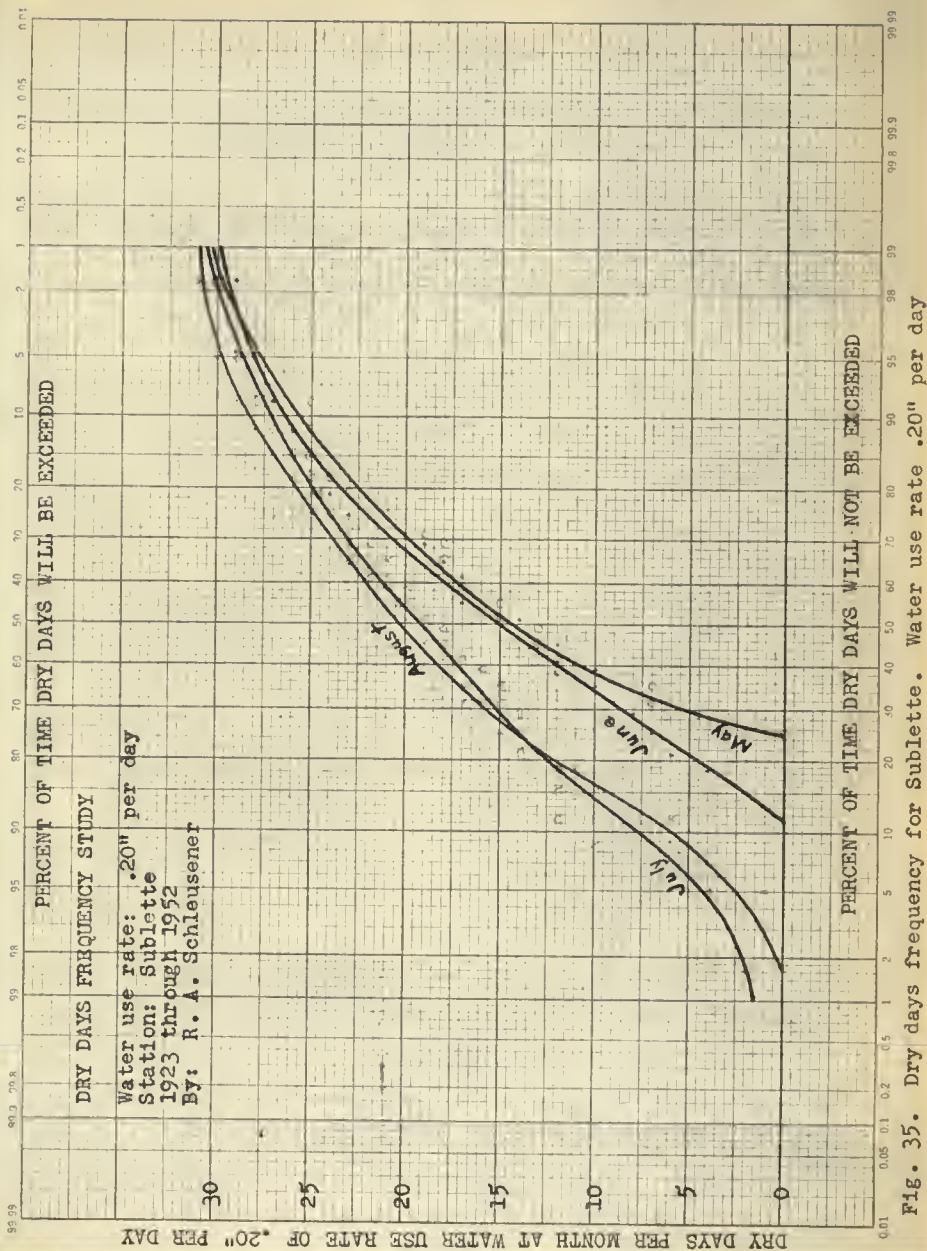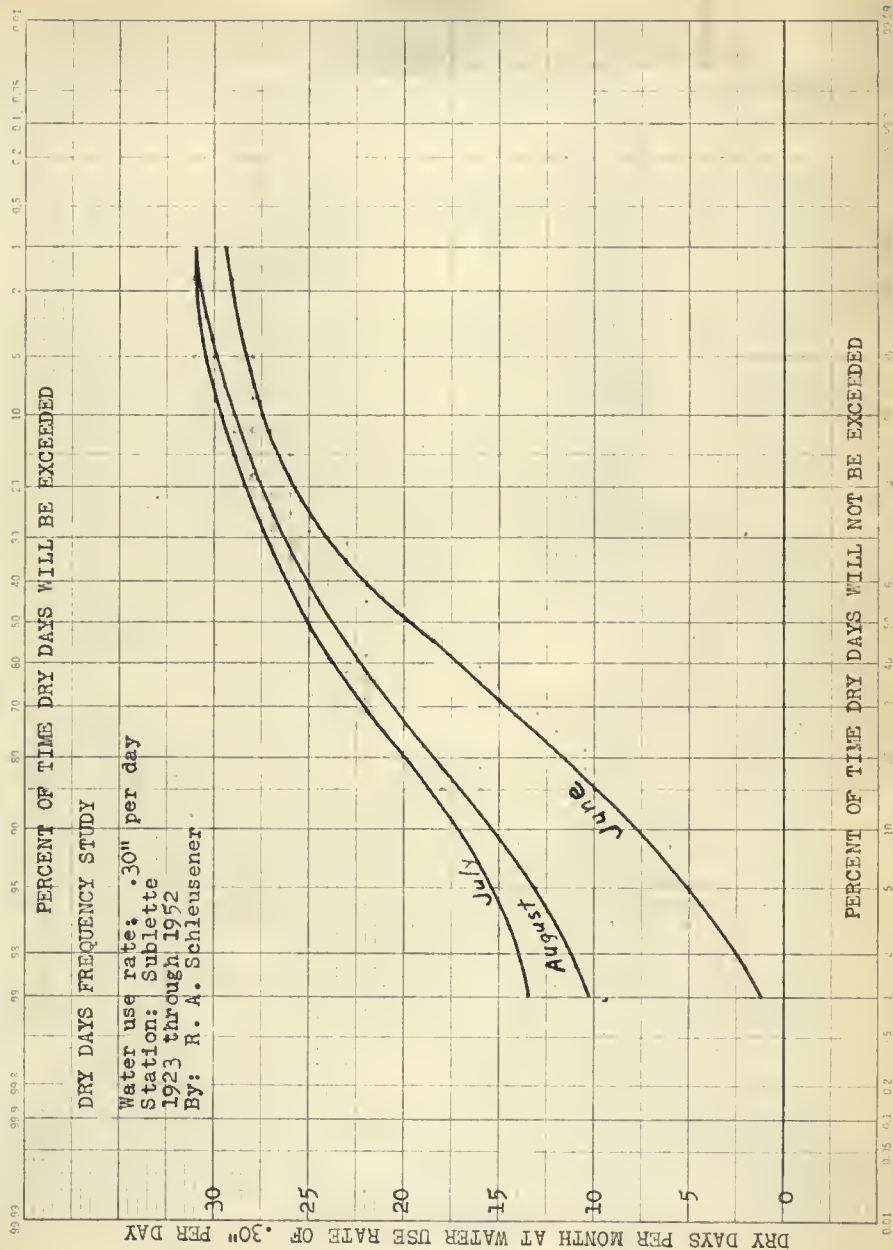
Fig. 36. Dry days frequency for Sublette. Water use rate .30" per day.
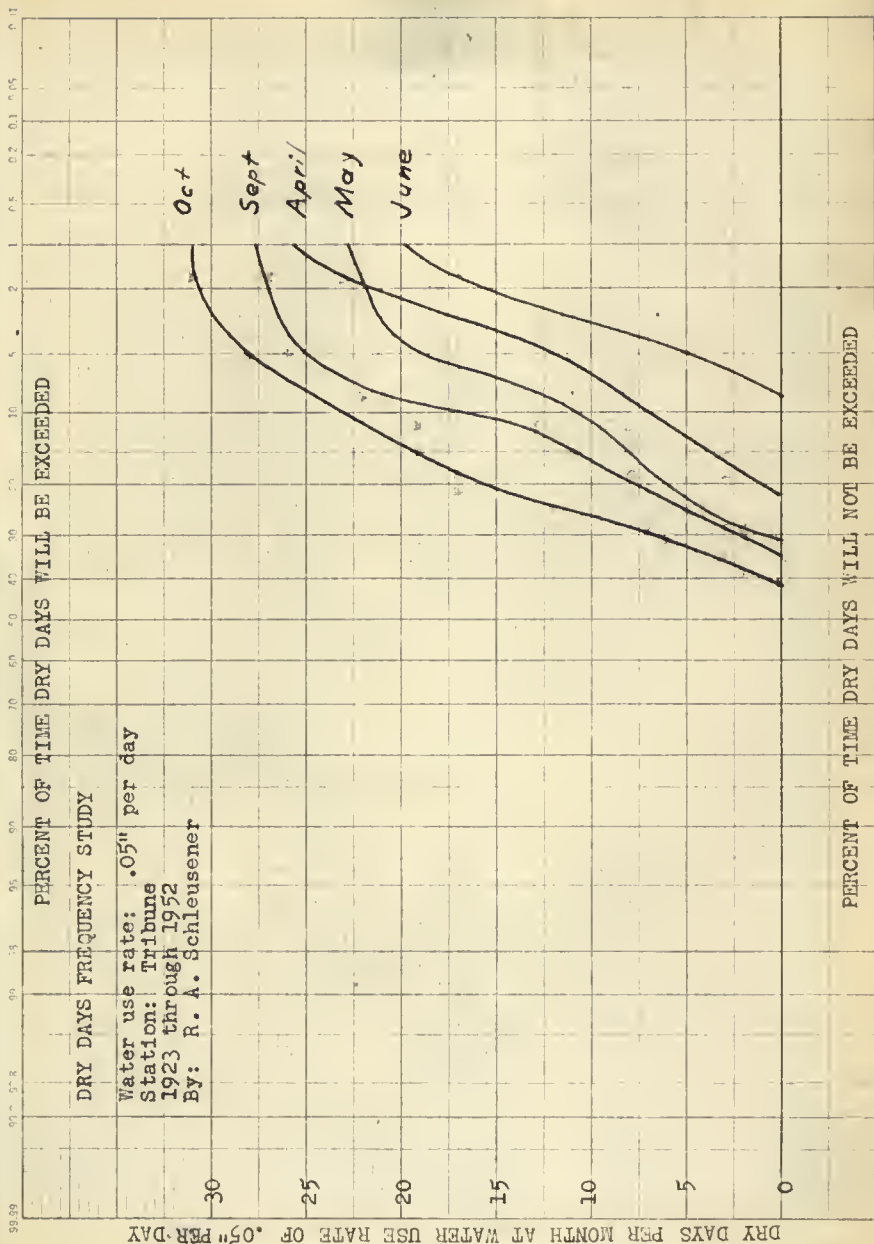
Fig. 37. Dry days frequency for Tribune. Water use rate .05" per day.

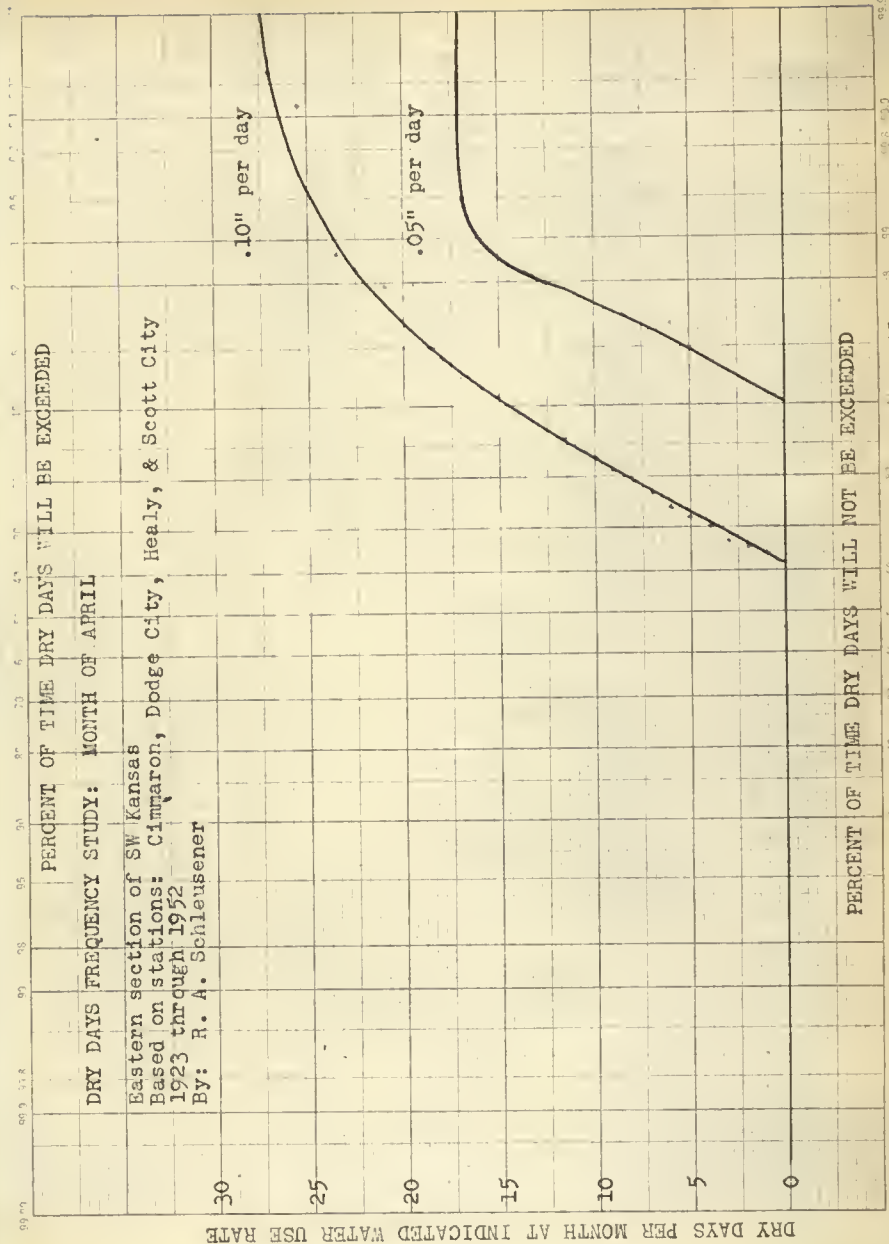Fig. 38. Dry days frequency for Tribune. Water use rate .10" per day.

Fig. 39. Dry days frequency for Tribune. Water use rate .20" per day.

DRY DAYS FREQUENCY STUDY

Water use rate: .20" per day
Station: Tribune
1923 through 1952
By: R. A. Schleusener

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT WATER USE RATE OF .20" PER DAY
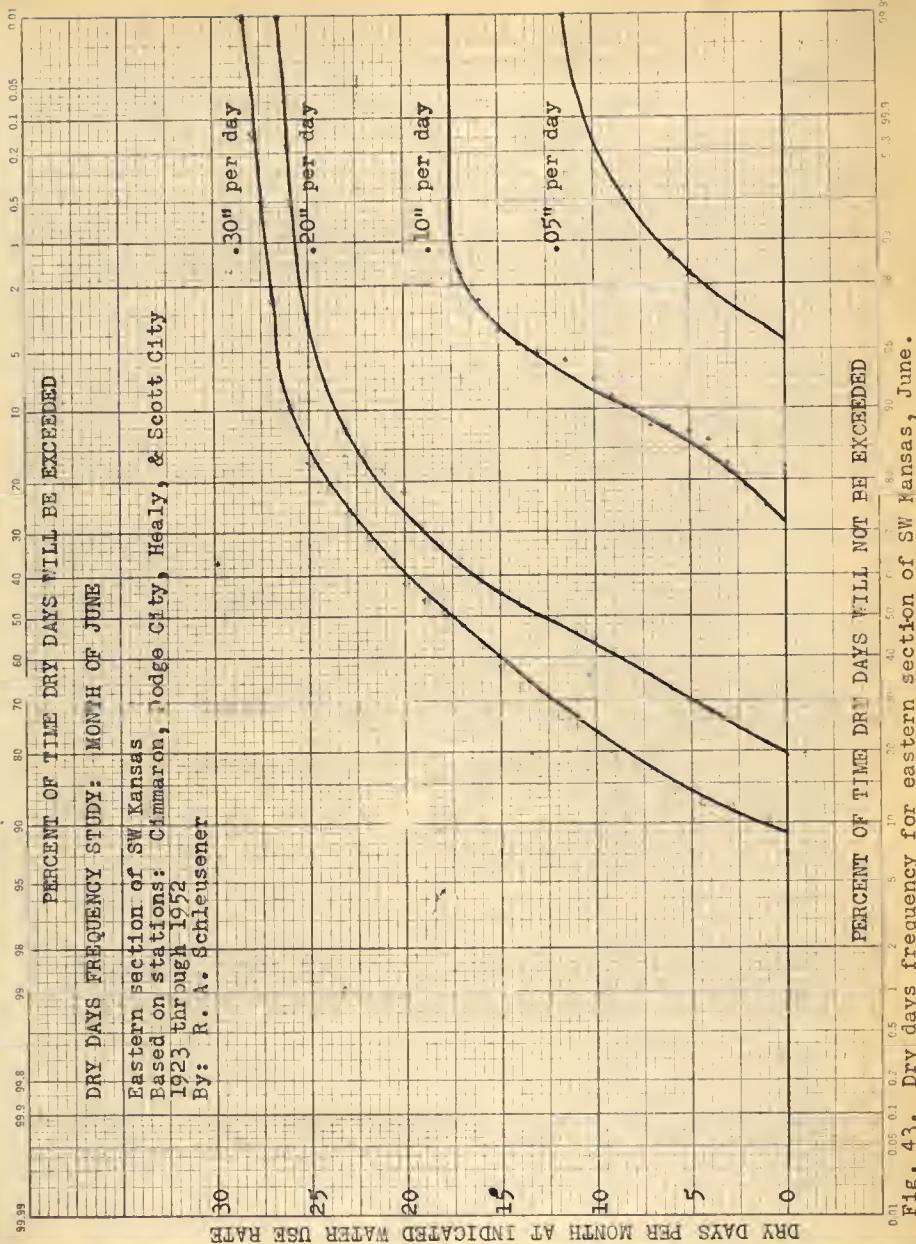
Fig. 40. Dry days frequency for Tribune. Water use rate .30" per day.

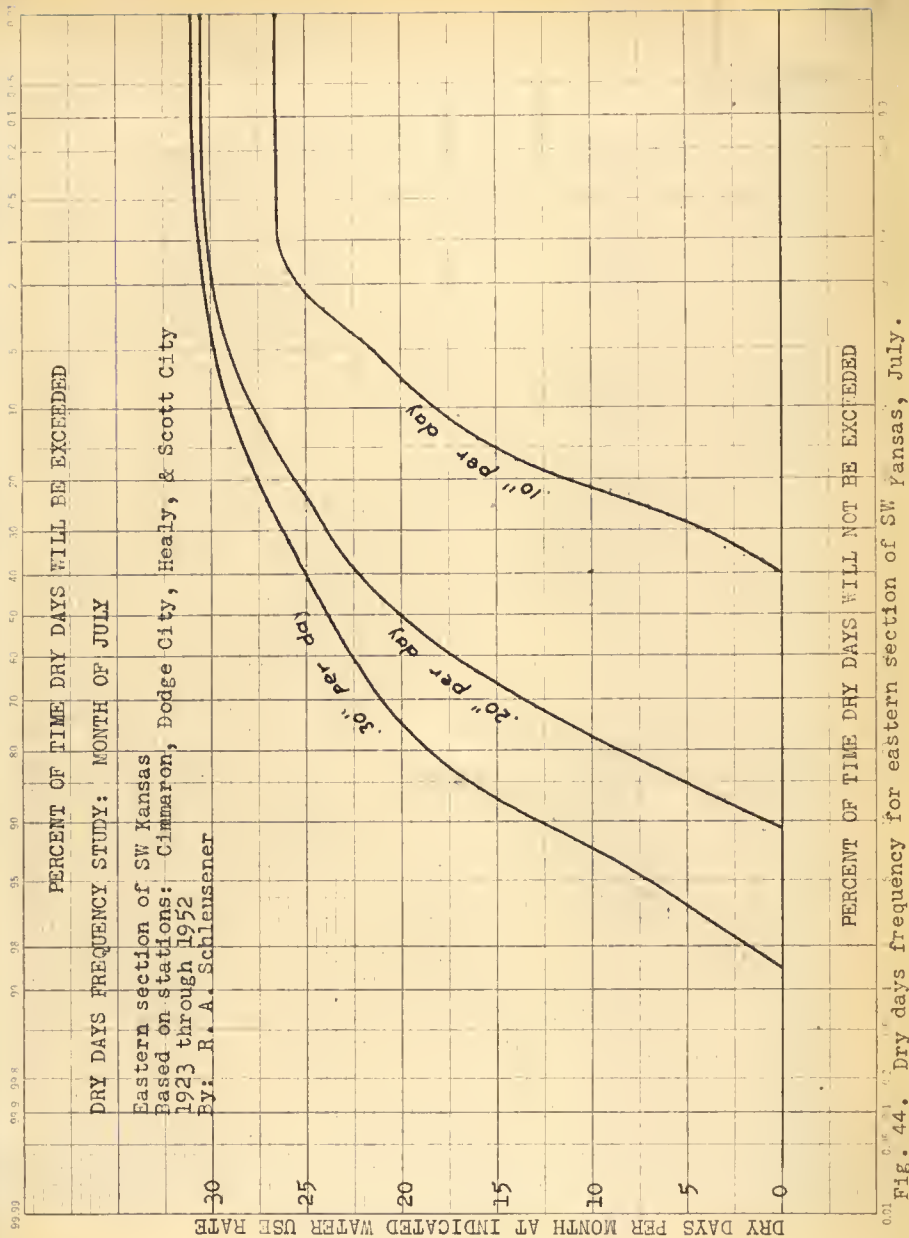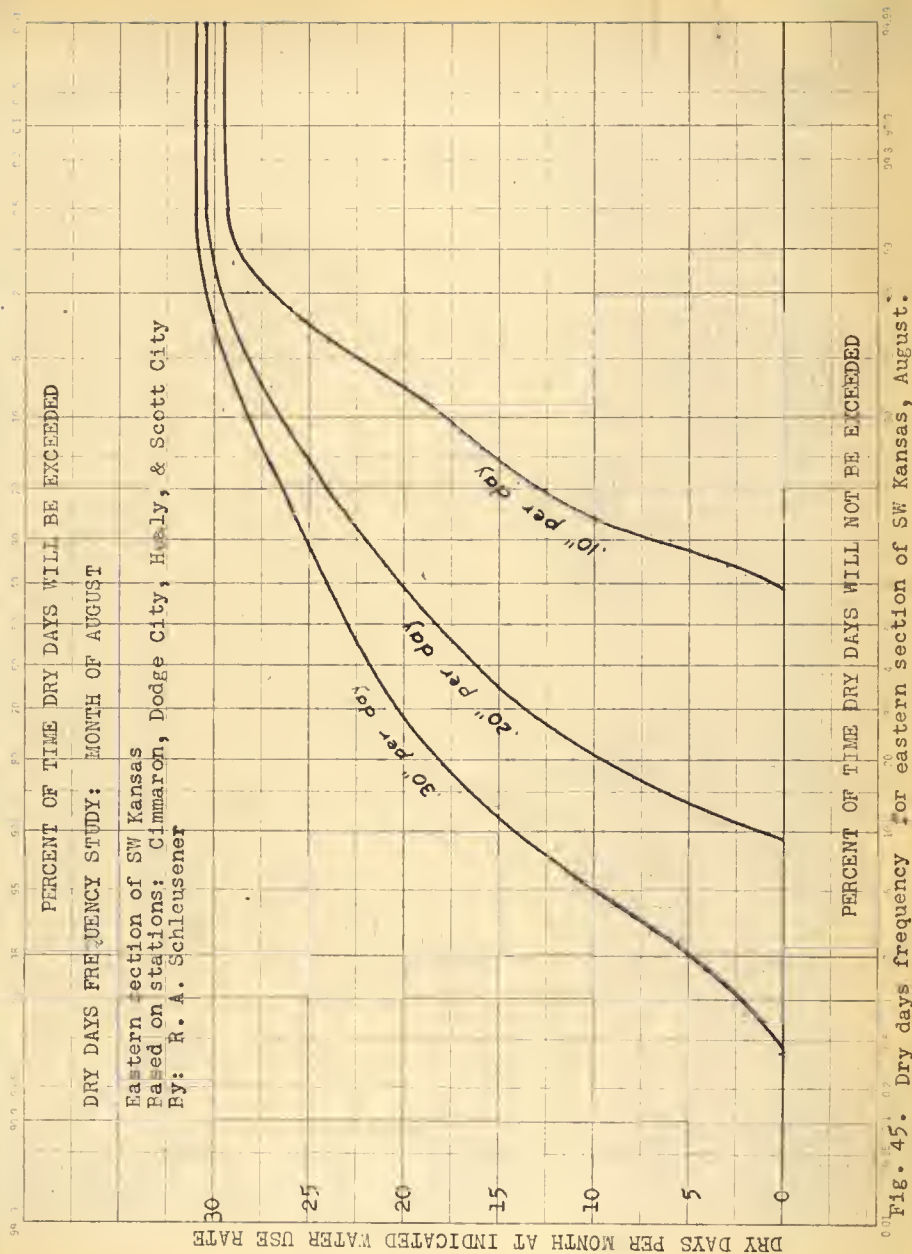Fig. 41. Dry days frequency for eastern section of SW Kansas, April

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF MAY

Eastern section of SW Kansas
Based on stations: Cimarron, Dodge City, Healy, & Scott City
1923 through 1952
By: R. A. Schleusener

.20" per day
.10" per day
.05" per day

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED
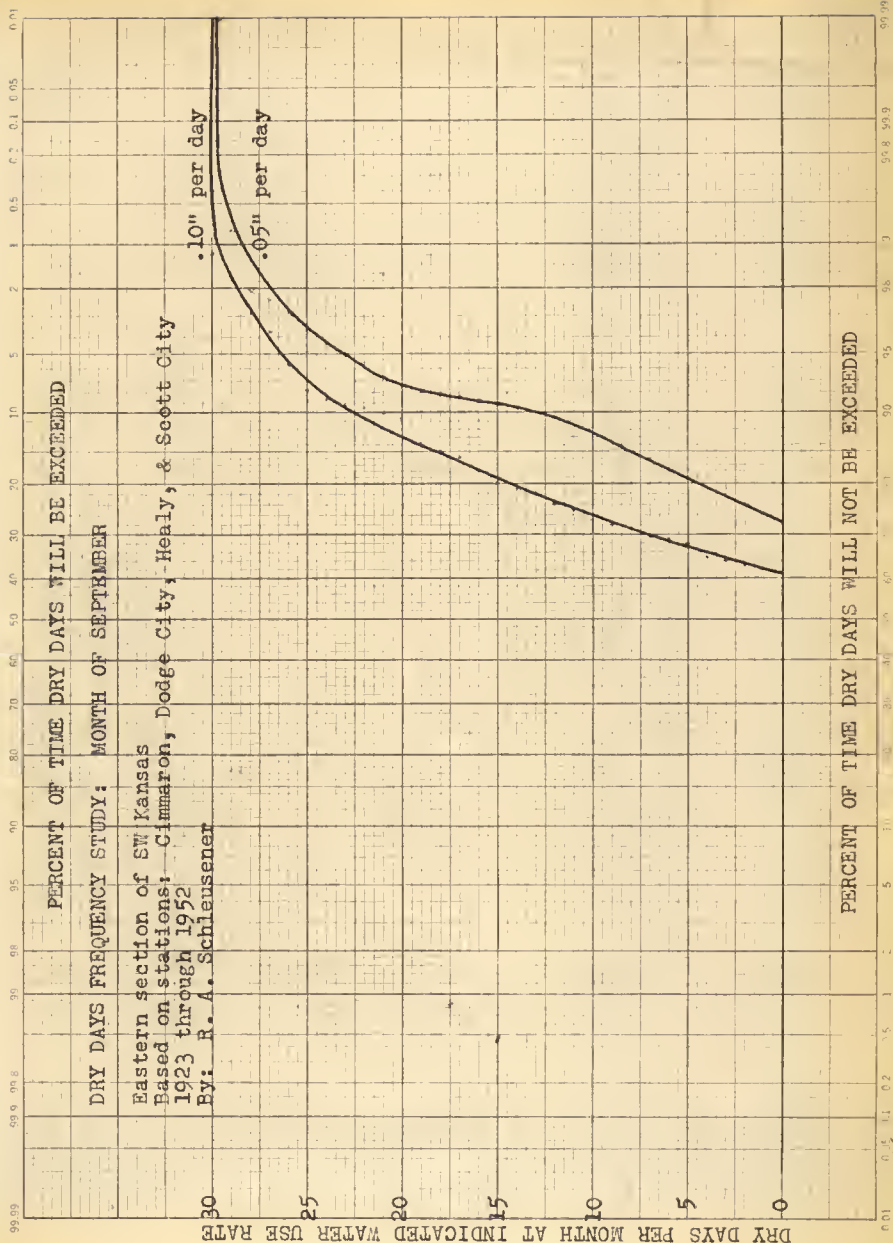
Fig. 42. Dry days frequency for eastern section of SW Kansas, May.

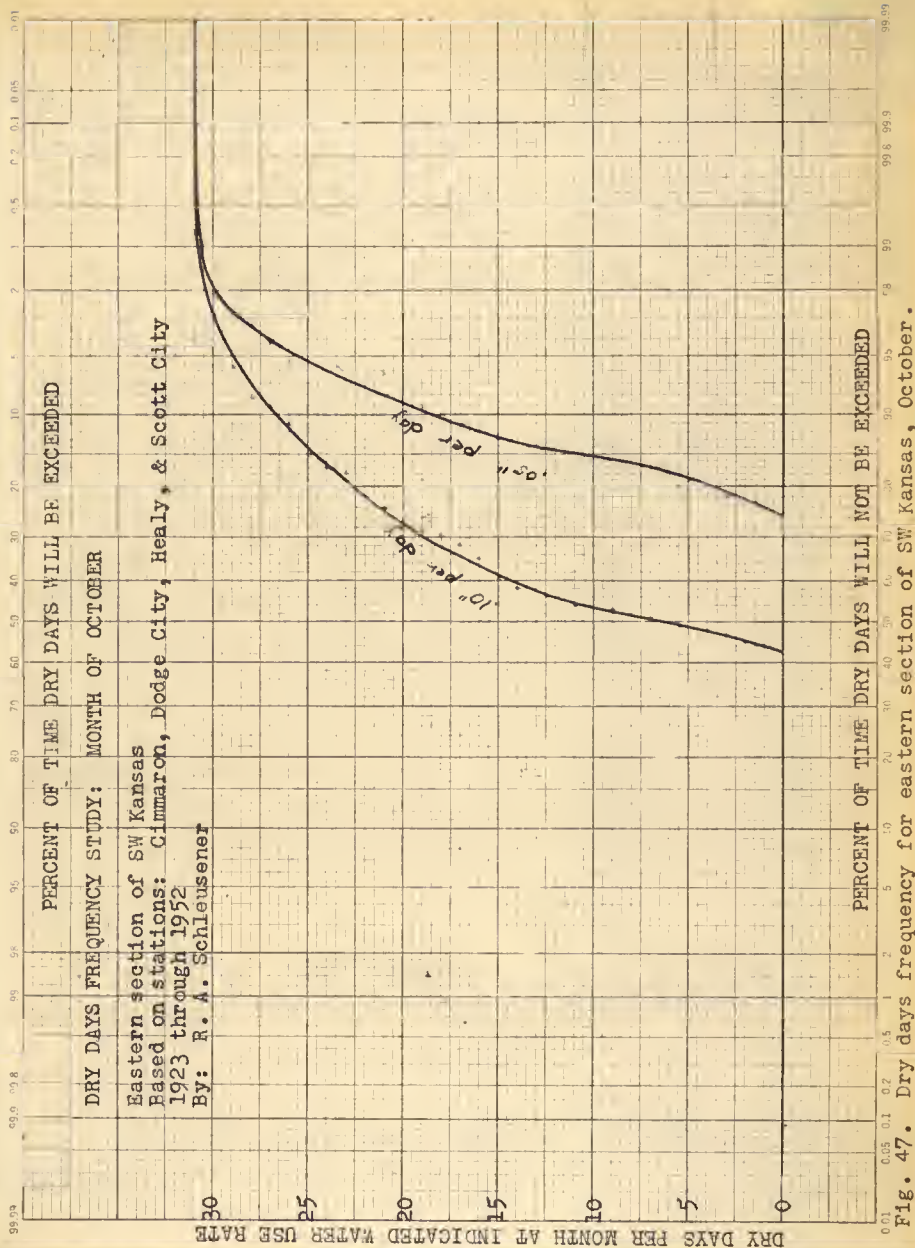Fig. 43. Dry days frequency for eastern section of SW Kansas, June.

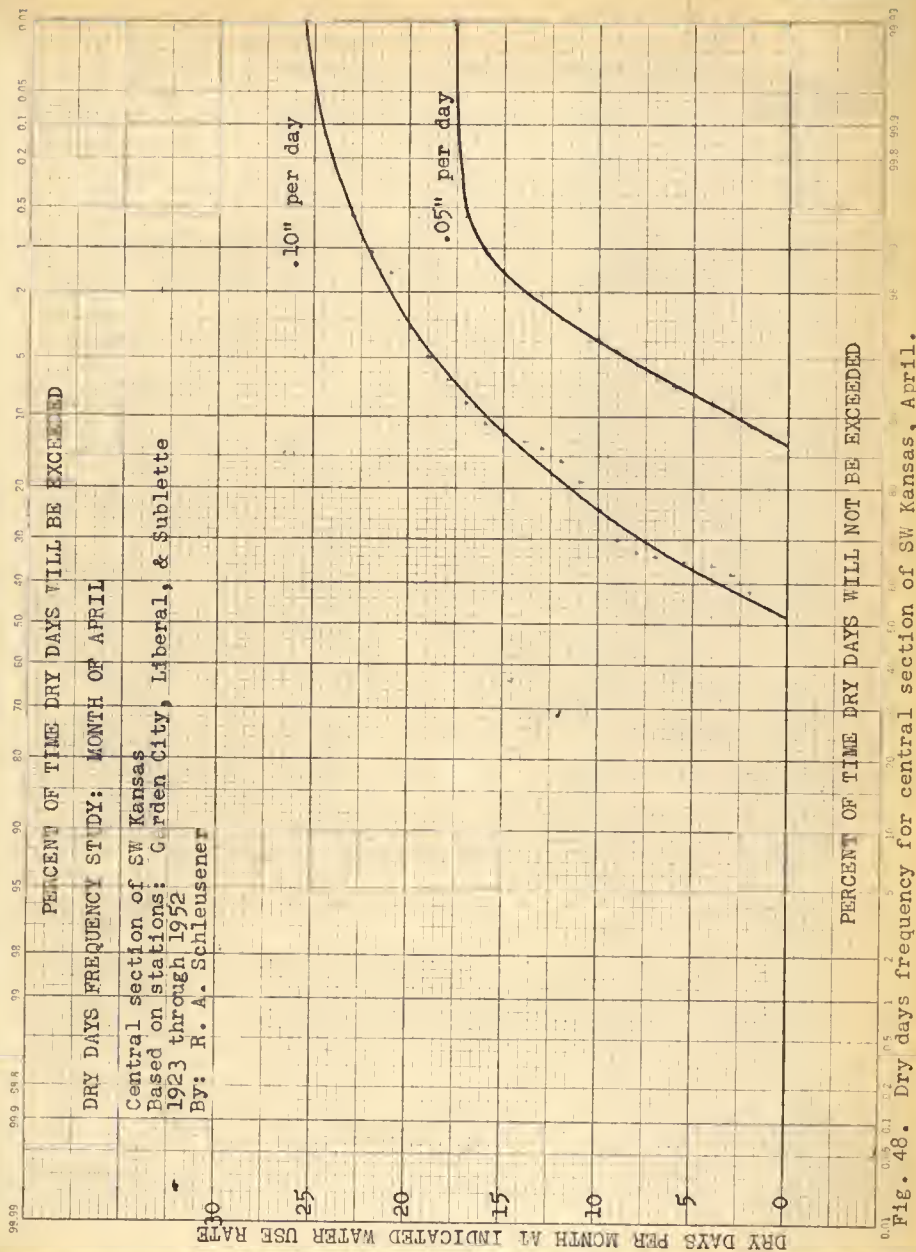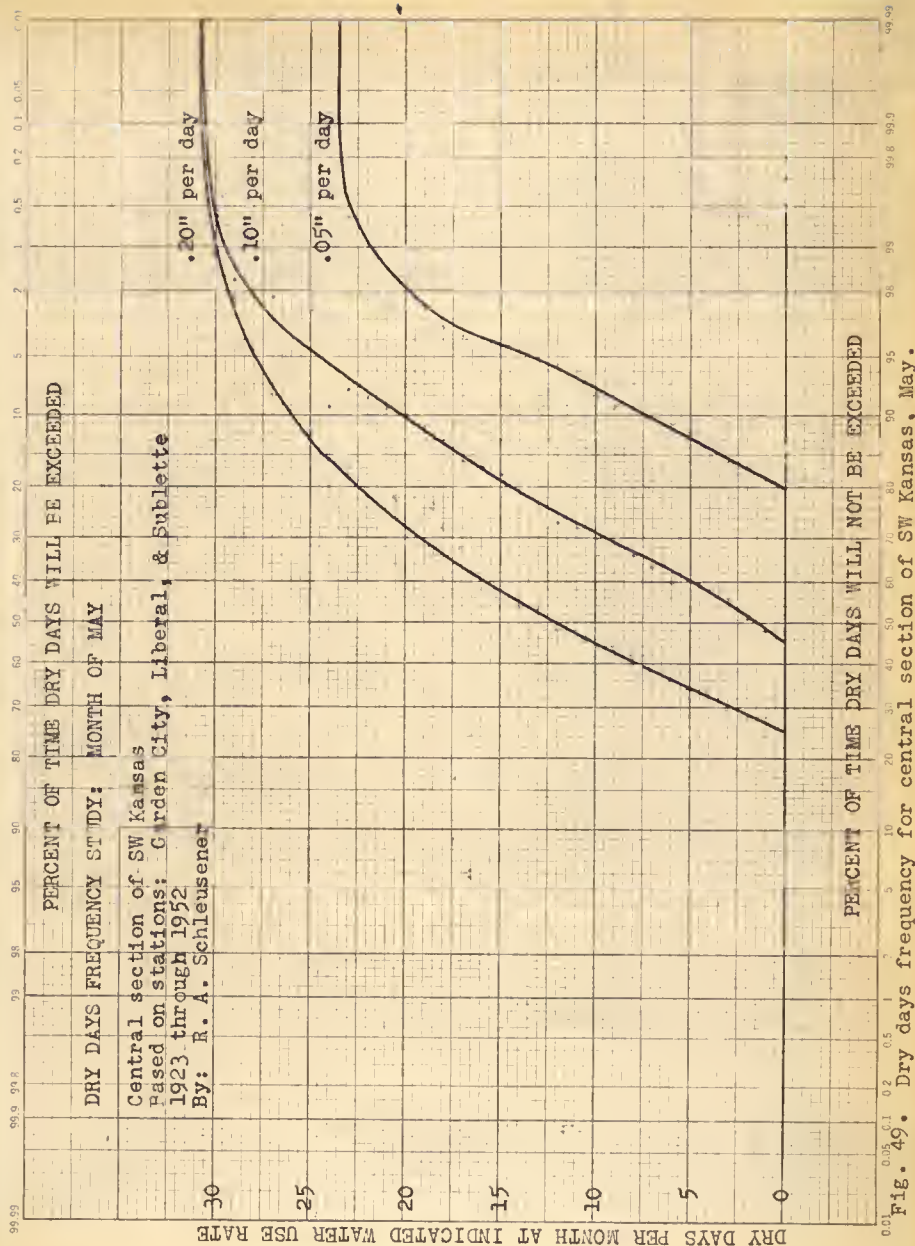PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF JULY

Eastern section of SW Kansas
Based on stations: Cimarron, Dodge City, Healy, & Scott City
1923 through 1952
By: R. A. Schleusener

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

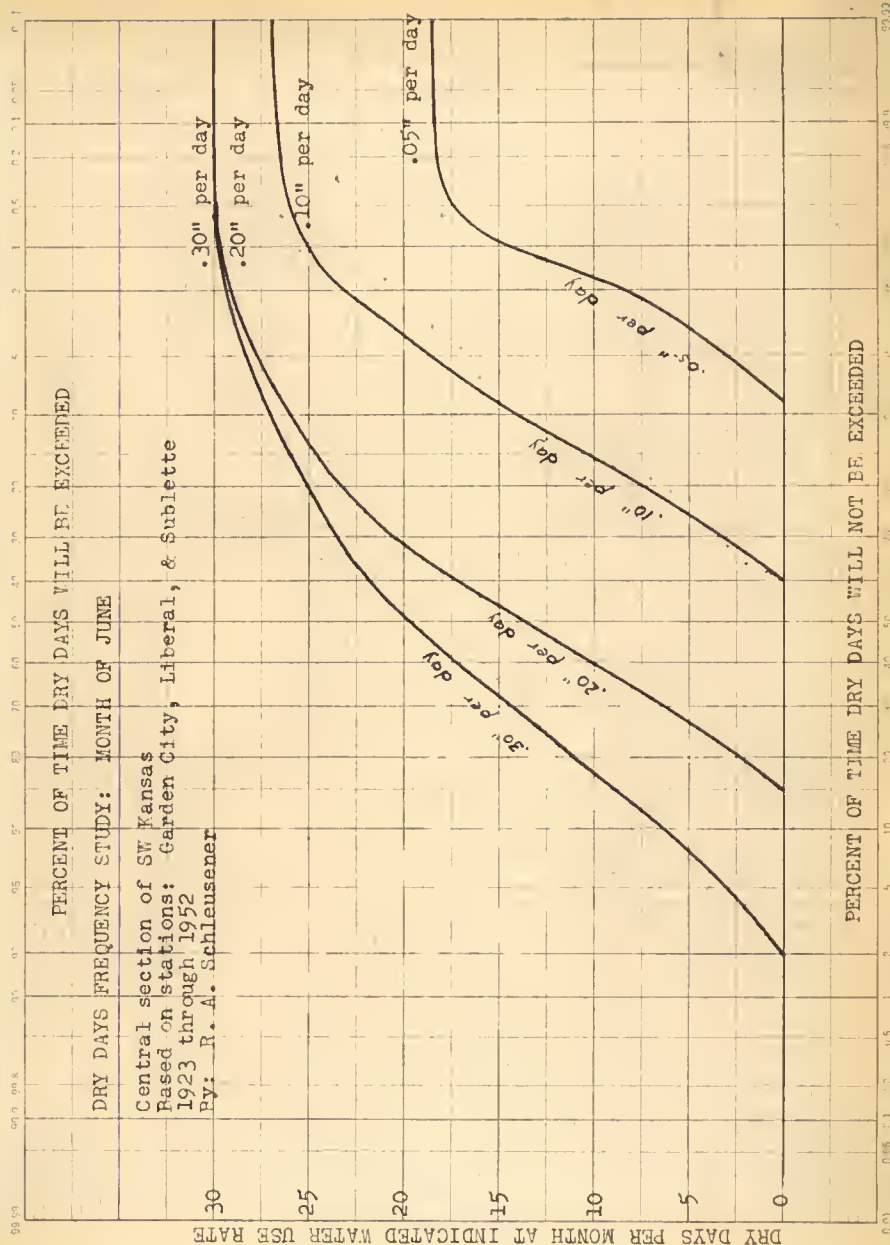Fig. 44. Dry days frequency for eastern section of SW Kansas, July.

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF AUGUST

Eastern section of SW Kansas
Based on stations: Cimmaron, Dodge City, Healy, & Scott City
By: R. A. Schleusener

'10" per day'

'20" per day'

'30" per day'

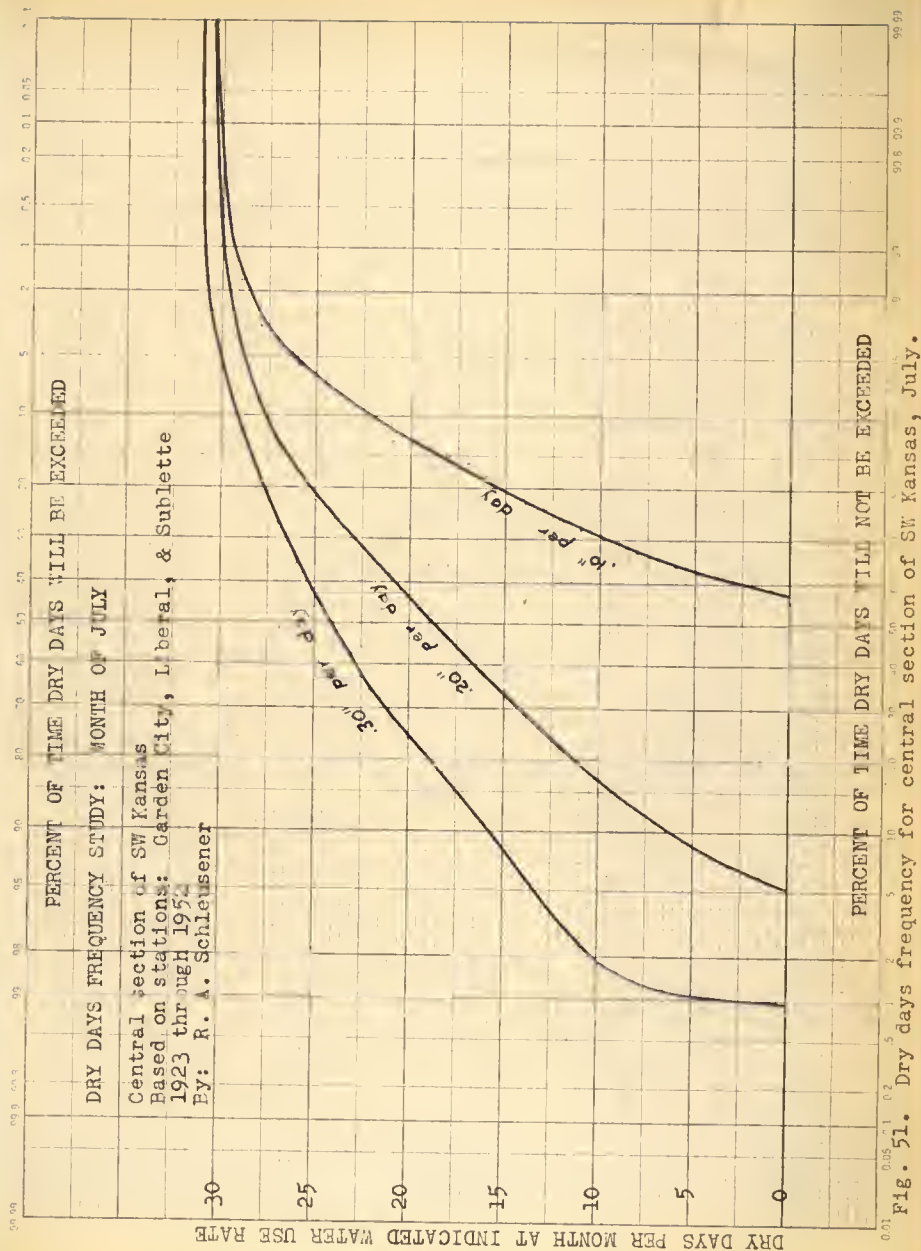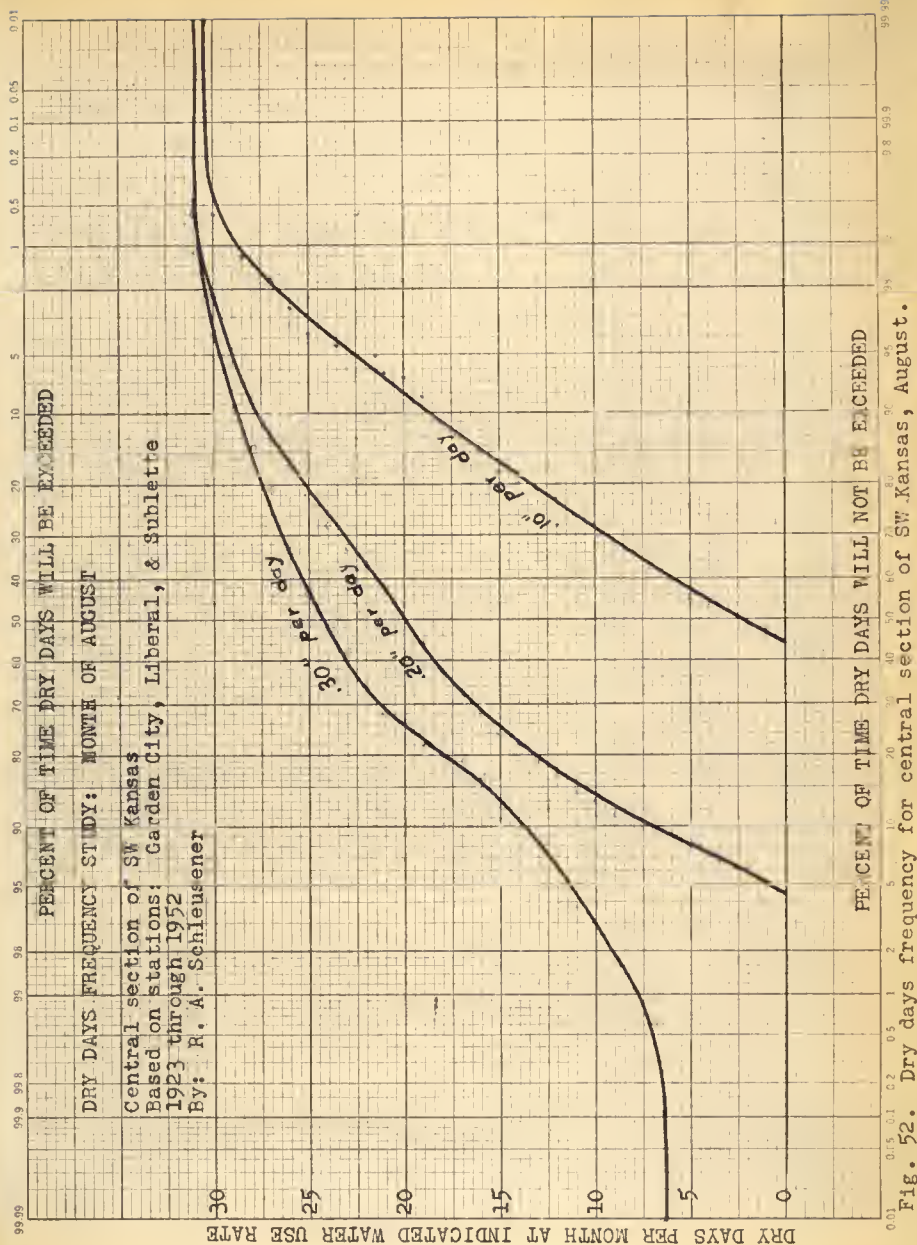PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT INDICATED WATER USE RATE
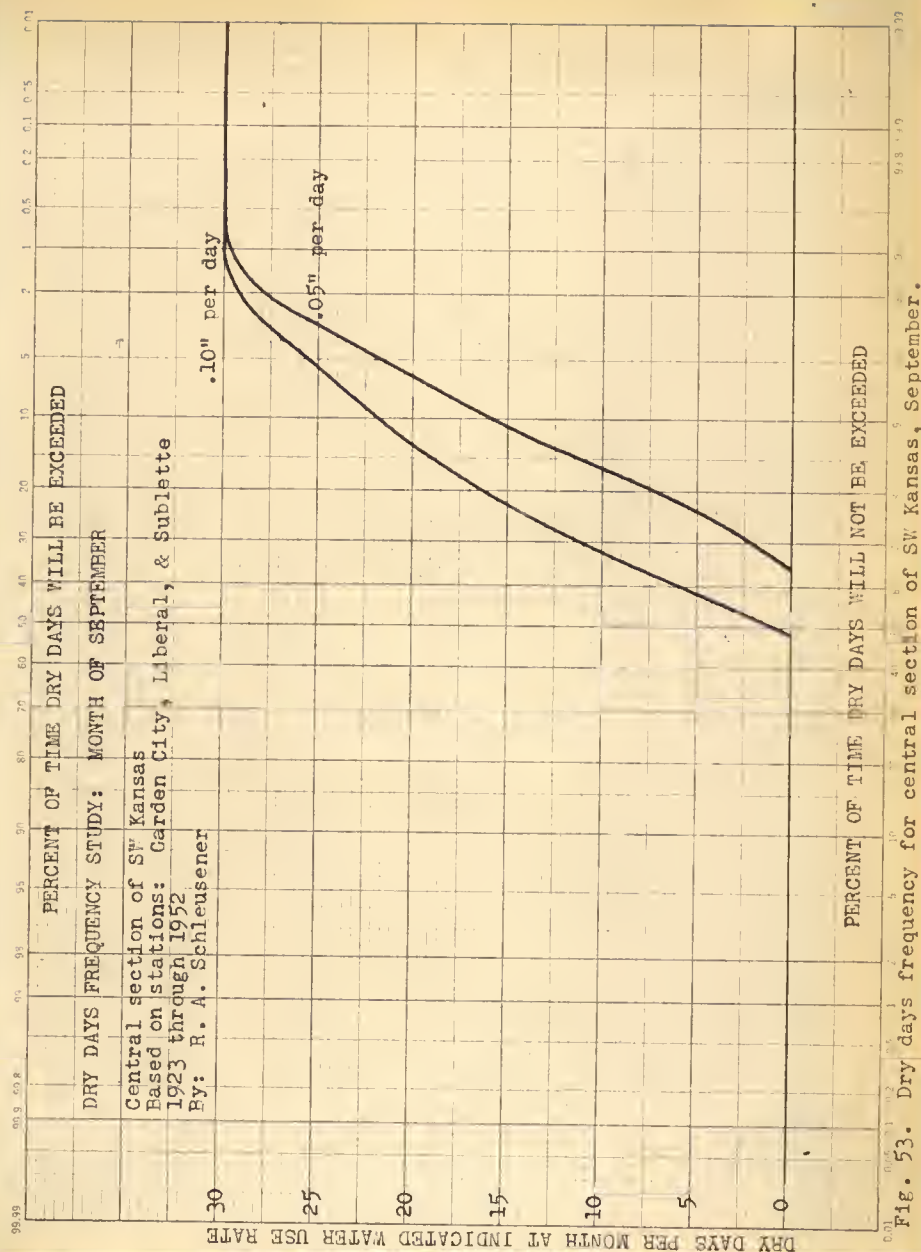
Fig. 45. Dry days frequency for eastern section of SW Kansas, August.

Fig. 46. Dry days frequency for eastern section of SW Kansas, September.

DRY DAYS FREQUENCY STUDY: MONTH OF SEPTEMBER

Eastern section of SW Kansas
Based on stations: Cimarron, Dodge City, Healy, & Scott City
1923 through 1952
By: R. A. Schleusener

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

.10" per day

.05" per day

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF OCTOBER

Eastern section of SW Kansas
Based on stations: Cimarron, Dodge City, Healy, & Scott City
1923 through 1952
By: R. A. Schleusener

.5" per day

10" per day

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

Fig. 47. Dry days frequency for eastern section of SW Kansas, October.

Fig. 48. Dry days frequency for central section of SW Kansas, April.

Fig. 49. Dry days frequency for central section of SW Kansas, May.

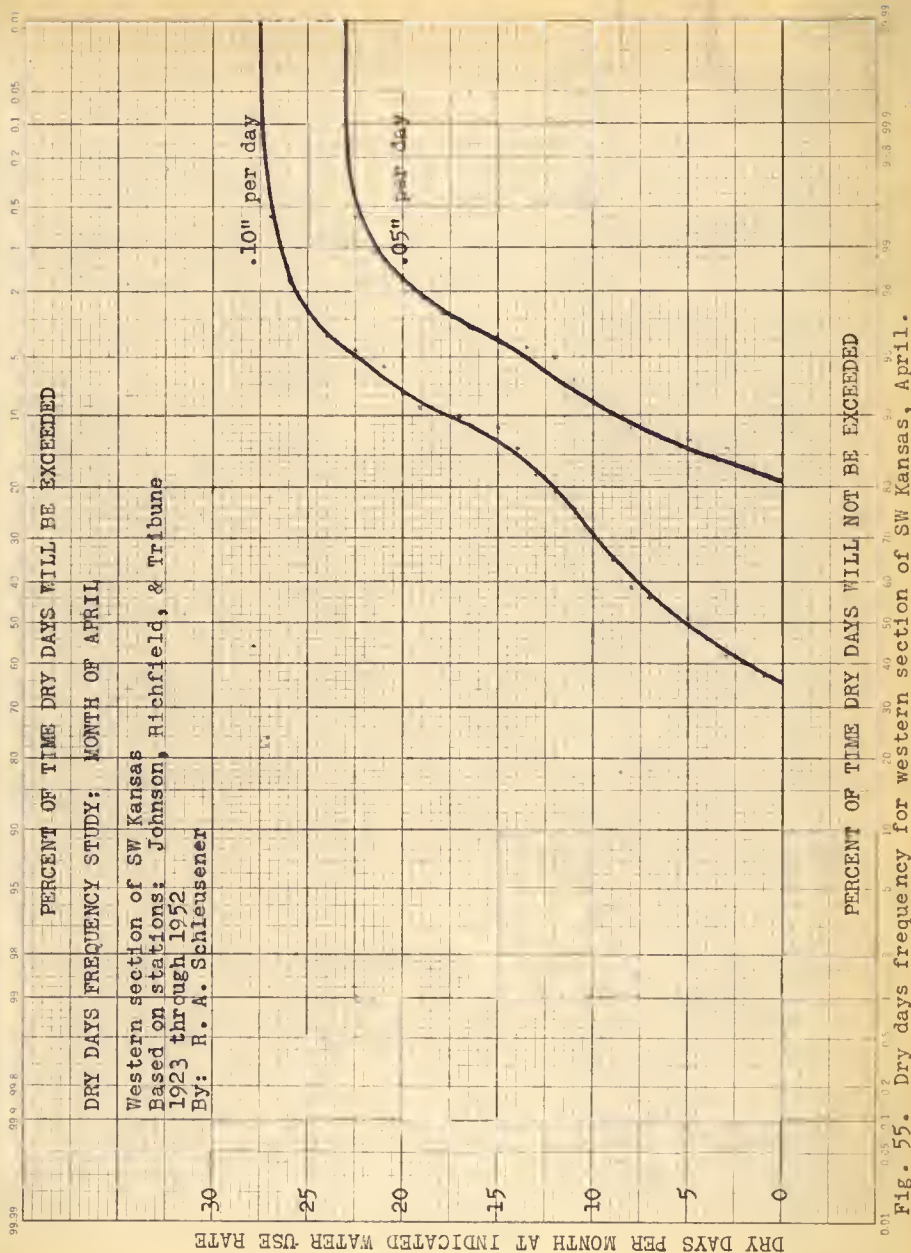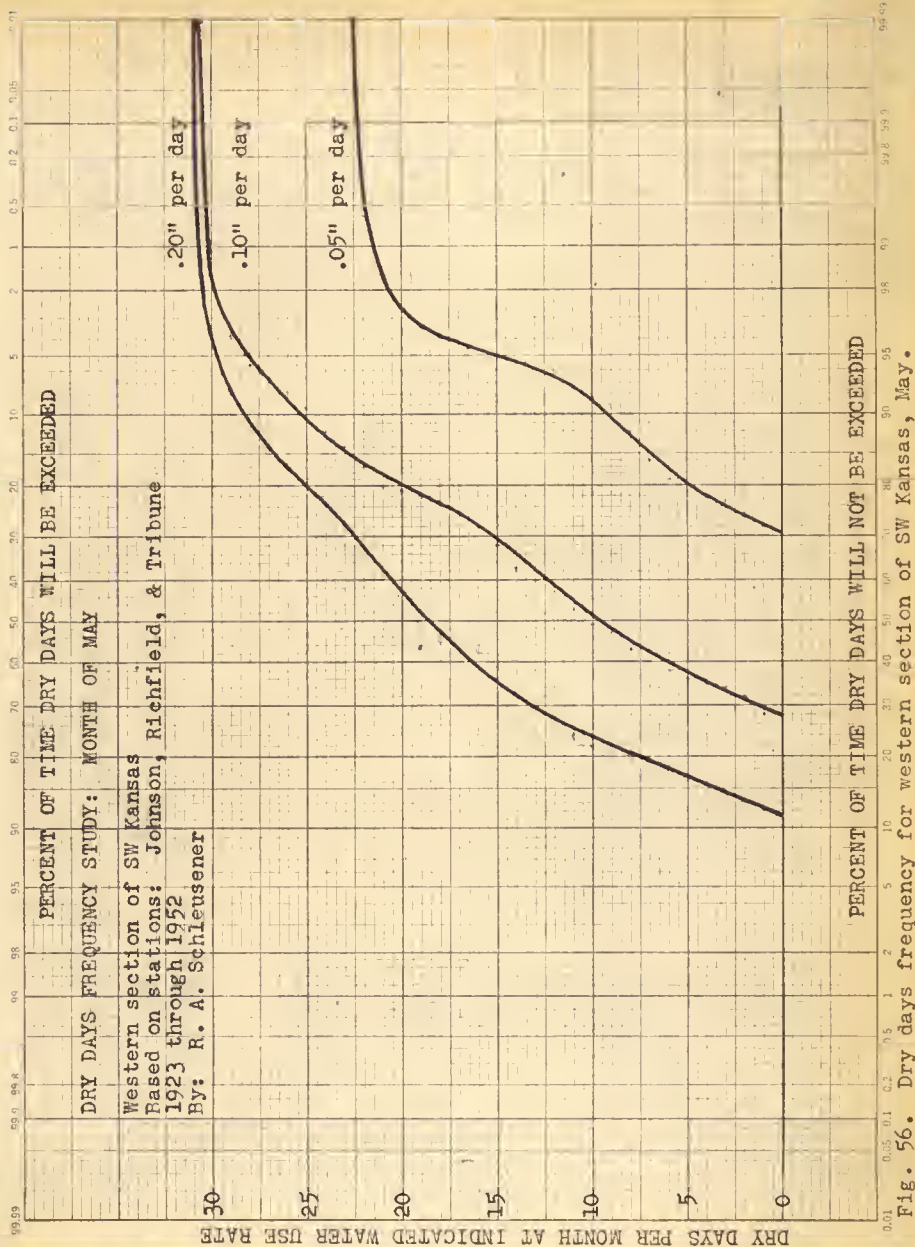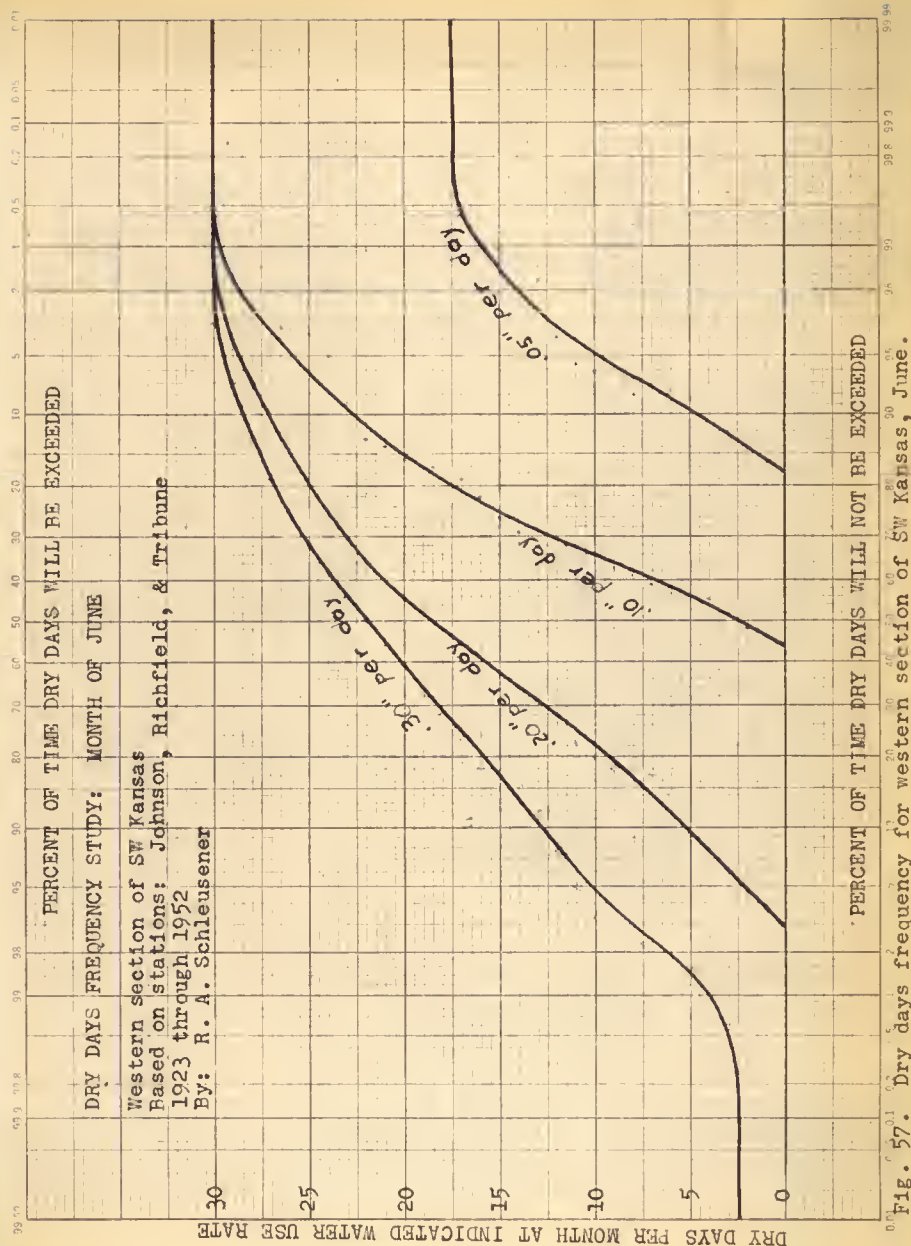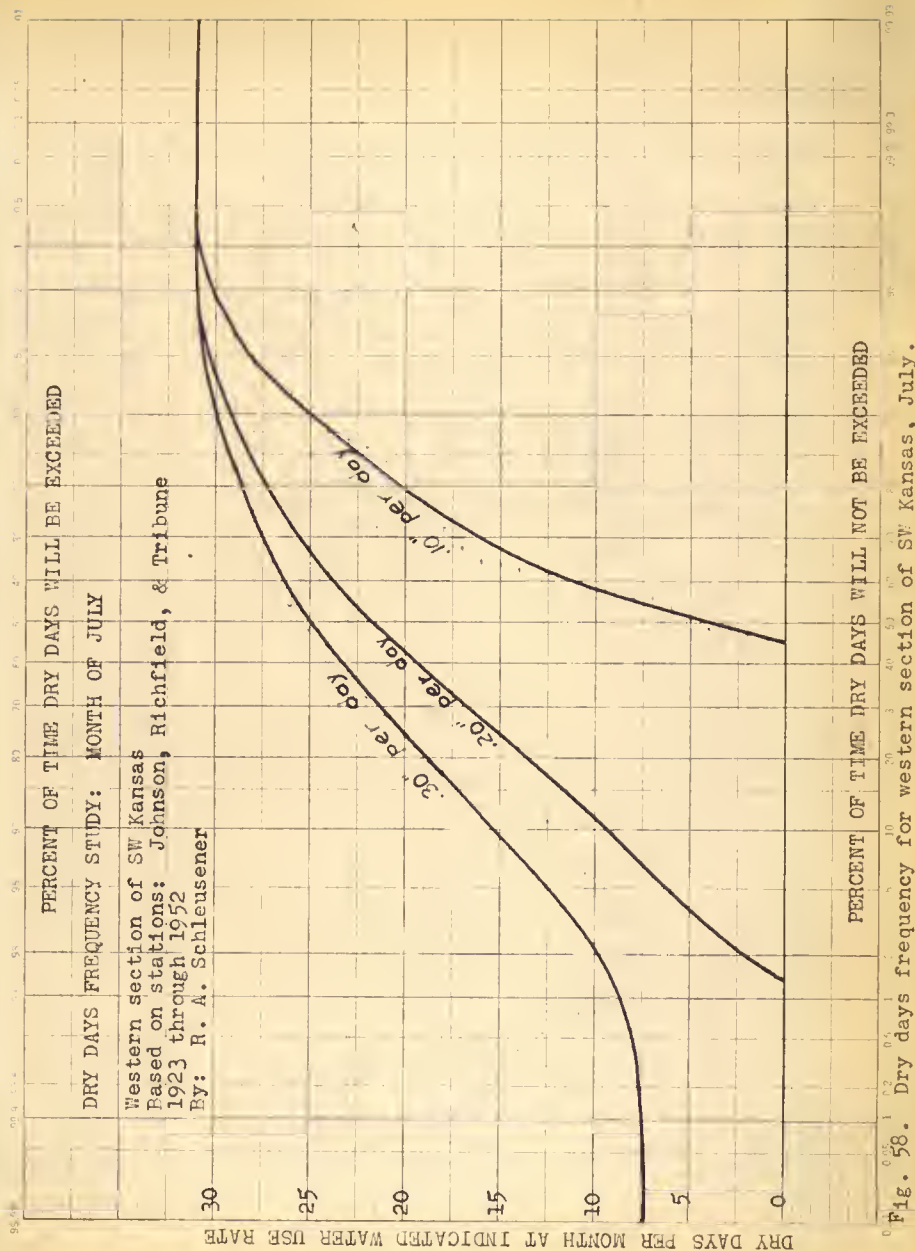Fig. 50. Dry days frequency for central section of SW Kansas, June.

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF JUNE

Central section of SW Kansas
Based on stations: Garden City, Liberal, & Sublette
1923 through 1952
By: R. A. Schleusener

.30" per day
.20" per day
.10" per day
.05" per day

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

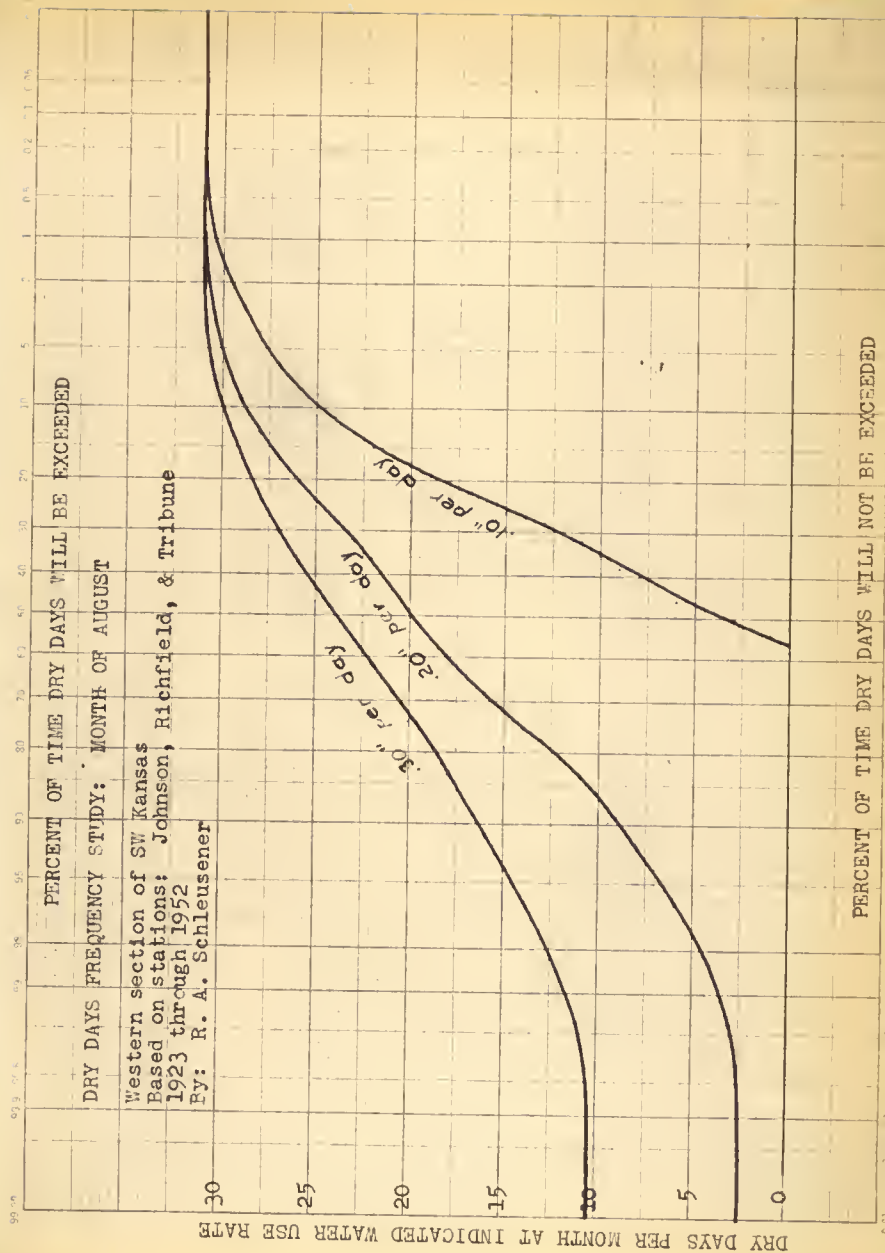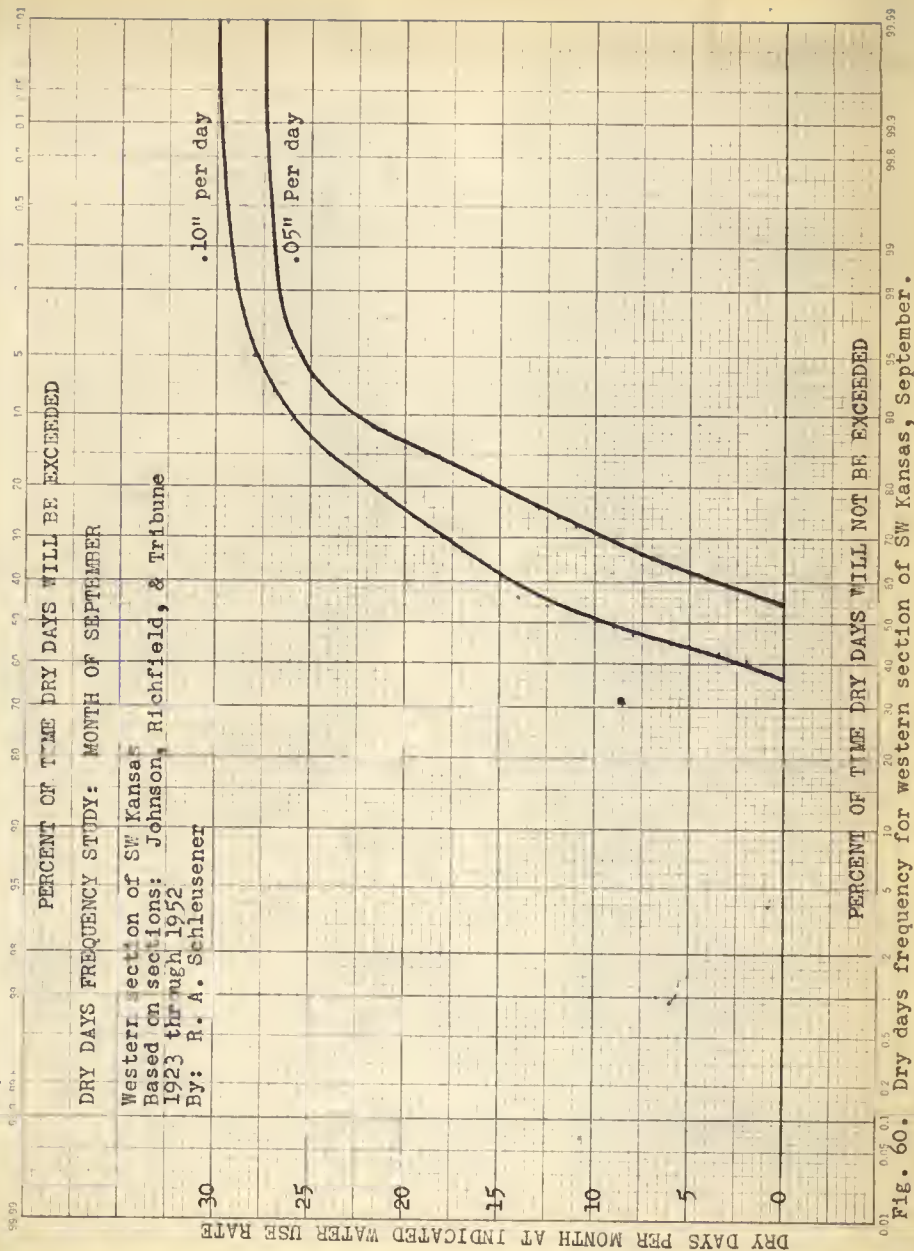Fig. 51. Dry days frequency for central section of SW Kansas, July.

PERCENT OF TIME DRY DAYS WILL BE EXCEEDED

DRY DAYS FREQUENCY STUDY: MONTH OF AUGUST

Central section of SW Kansas
Based on stations: Garden City, Liberal, & Sublette
1923 through 1952
By: R. A. Schleusener

PERCENT OF TIME DRY DAYS WILL NOT BE EXCEEDED

DRY DAYS PER MONTH AT INDICATED WATER USE RATE

10" per day

20" per day

30" per day

Fig. 52. Dry days frequency for central section of SW Kansas, August.

Fig. 53. Dry days frequency for central section of SW Kansas, September.

Fig. 54. Dry days frequency for central section of SW Kansas, October.

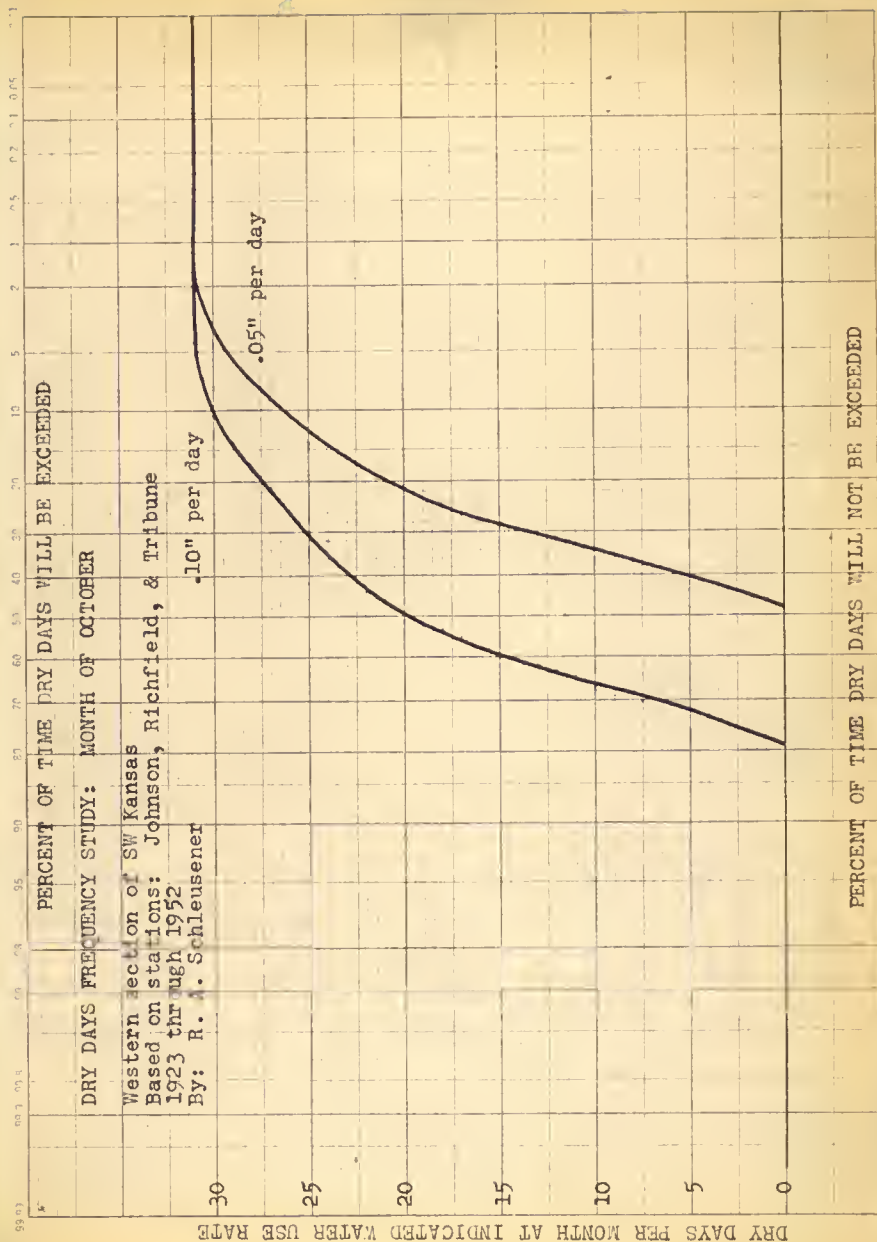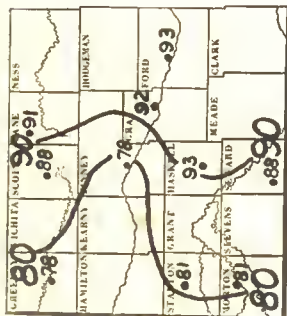Fig. 55. Dry days frequency for western section of SW Kansas, April.

Fig. 56. Dry days frequency for western section of SW Kansas, May.

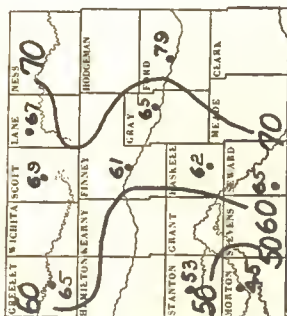Fig. 57. Dry days frequency for western section of SW Kansas, June.

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Fig. 58. Dry days frequency for western section of SW Kansas, July.

Fig. 59. Dry days frequency for western section of SW Kansas, August.

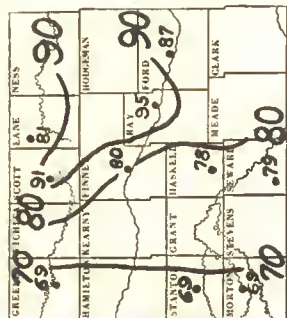Fig. 60. Dry days frequency for western section of SW Kansas, September.

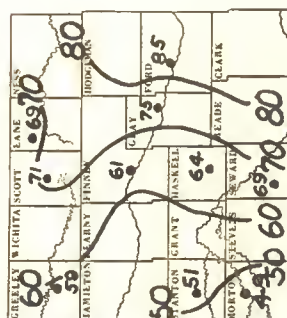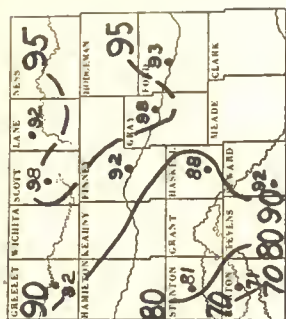Fig. 61. Dry days frequency for western section of SW Kansas, October.

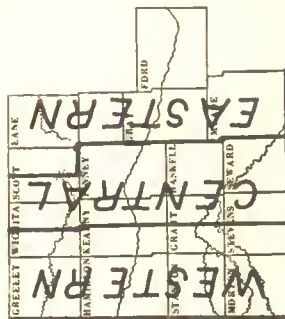Fig. 62. Analysis of SW Kansas for areas of similar dry days characteristics.

Iso-lines are percent of time less than one dry day occurs at water use rate of .051 inch per day. Data for individual stations obtained from figures 1,5,9,14,17,21,25,29,33, and 37.

Division of area into sections, based on similar dry days characteristics.

PRECIPITATION AND DROUGHT FREQUENCIES FOR SOUTHWESTERN
KANSAS AS RELATED TO VARIOUS CROP WATER USE RATES

by

RICHARD AUGUST SCHLEUSENER

B. S., University of Nebraska, 1949

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1956

Variability of precipitation amounts and frequency is
present to a high degree in the state of Kansas. Because
of this variability, average values of precipitation amounts
or moisture deficient periods are inadequate to analyze
correctly precipitation and drought frequencies in the Kansas
area. A more complete analysis is given by a frequency
analysis. The purpose of this study was to analyze precipi-
tation records from a section of southwestern Kansas, to
obtain a frequency distribution of moisture deficient periods
as related to various crop water use rates.

The drought period used in this study was a "dry day",
defined as a day in which the soil moisture reservoir had
no available moisture for plant growth. The total moisture
deficit was then equal to the number of "dry days" multiplied
by the crop water use rate.

Sixteen counties in the southwestern section of Kansas
were selected for study. Ten stations were selected from
the area, based on uniform coverage of the area, and adequate
length of precipitation records.

A "bank account procedure" was followed wherein crop
water use rates of .05, .10, .20, and/or .30 inch per day
were assumed to be drawing on the soil moisture "account."
Natural precipitation was credited to the available moisture
in the soil moisture account. The number of "dry days" in
which no moisture was available in the soil moisture "account"
was noted for each month of the growing season for thirty

years of record, 1923 through 1952. The results were prepared
in the form of graphs plotted as percent probability vs.
number of dry days per month for each station for each applicable
water use rate and for each of the months of the growing season.

Data from the ten individual stations were then combined.
Analysis of data showed that, based on similar "dry days"
characteristics, the entire southwestern Kansas area could be
subdivided west to east into three similar sections. Data
from all stations within each section were then combined to
form a record based on a greater number of station years.
Data from each section were then prepared in the form of
graphs plotted as percent probability vs. number of dry days
per month for each month, for each applicable crop water use
rate.

The frequency of dry days per month are presented in
graphical form for each of the ten stations selected for study,
for each month, for each applicable water use rate.

Similar graphs are given for each section of the south-
western Kansas area.

Examples are given of how these data may be used. They
may be used for making an estimate of irrigation requirements,
on a probability basis, when the crop consumptive use can be
estimated. They may be used in making an estimate of the
probability that natural precipitation would supply the water
that could be applied by winter irrigation. They may be used

for making an estimate, on a probability basis, of water
requirements for winter irrigation. Finally, they may be
used in making an evaluation of the drought hazard to
dry land crops.